EE4: Small Solar Vehicle

Louis XIV

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Introduction

The report contains the entire project around the SSV LOUIS XIV. It is divided in three different E's: Engineering, Enterprising and Educating.

The Engineering part is the important part of the report. It gives more information about the studies with and on the SSV to finally reach the goal of the best SSV we could make. It exists of Case SSV part 1, Case Simulink and Case SSV part 2.

In this first case of the project we had to design the SSV or Small Solar Vehicle. It is important to choose which materials and structures will be used and how to implement them into the SSV. The final goal is to race other teams on a 14-meter track and finish first. To obtain this goal it is of utmost importance to prevent the car from colliding against one of the sidewalls. The designing elements had to be chosen wisely, to maintain a good balance between the weight and the robustness of the car. First, the design of the SSV will be explained. An argumentation about the choice of materials and design will be given. Next, some required parameters of the solar panel will be calculated. Using these and other designed parameters several gear ratios will be calculated. Using Matlab and Simulink we create simulations of the performance of our SSV. These simulations will determine the best gear ratio. Using this ratio we give a numerical calculation of the displacement and speed for the first second during the race. Finally, the different losses of the SSV will be calculated in two different situations. These losses will be displayed in a Sankey diagram. Case Simulink contains the three simulations that had to be studied and every simulation holds a discussing of how it works and what the results are. Case part 2 exists first of the simulation for a better Sankey Diagram. This has been obtained by the test drive we had to do with our prototype. Secondly there is a section about analysis of the critical loaded components on the driving shaft. The third section of case part 2 contains all the 2D drawings of the frame of the LOUIS XIV. The fourth and fifth sections are two cases that include impulse and fraction.

The Enterprising part gives the link to the Wikipage of the SSV LOUIS XIV.

In the Educating part the Cooperation Contract, Plan Of Approach, Work Breakdown Structure and the Gantt Chart are collected. There is also the final report with the reflection on our project.

The project is based on a real-life engineering situation where our team had to keep in mind that we were an engineering bureau and we had to give our contractor, the Umicore Solar Team, a solution to build a demo model of a Small Solar Vehicle.

1 Engineering

1.1 Case SSV Part 1

This paragraph starts with the characteristic of the solar panel. From the results of the characteristic, the optimal gear ratio for the SSV can be calculated. The design will be justified and the progress of the car will be determined in function of time. Last section will visualize the power drift in a Sankey diagram.

1.1.1 Determine characteristic of the solar panel

To determine the characteristic of the solar panel, the current and the output voltage were measured under a bright lamp. With these values the power and the diode factor were calculated.

To calculate the power of the solar panel, the following formula was used.

$$P = U * I$$

To calculate the diode factor of the solar panel, the following formula was used.

$$I = Isc - Is * (e^{\frac{U}{m*N*Ur}} - 1)$$

$$\frac{I - Isc}{-Is} = e^{\frac{U}{m*N*Ur}} - 1$$

$$\frac{Isc - I}{Is} + 1 = e^{\frac{U}{m*N*Ur}}$$

$$ln\left(\frac{Isc - I}{Is} + 1\right) = \frac{U}{m * N * Ur}$$

$$m = \frac{U}{N * Ur * \ln\left(\frac{Isc-I}{Is} + 1\right)}$$

With

$N = 15$	(number of solar cells in series)
$Ur = 25.7mV = 25.7 * 10^{-3}V$	(thermical voltage)
$Isc = (0.570 \pm 0.001)A$	(the short circuit current)
$Is = 1 * 10^{-8} \frac{A}{m^2}$	(saturation current)

Table 1: Measured and calculated values of the solar panel

U(V)	I(A)	P(W)	m
8,80	0,029	0,255	1,28
8,79	0,029	0,253	1,28
8,77	0,032	0,281	1,28
8,75	0,035	0,304	1,27
8,73	0,037	0,325	1,27
8,69	0,040	0,351	1,27
8,67	0,039	0,336	1,26
8,63	0,042	0,364	1,26
8,61	0,044	0,375	1,25
8,59	0,047	0,404	1,25
8,57	0,048	0,407	1,25
8,56	0,047	0,400	1,25
8,54	0,046	0,395	1,25
8,52	0,050	0,423	1,24
8,51	0,054	0,461	1,24
8,50	0,056	0,479	1,24
8,46	0,066	0,558	1,24
8,44	0,071	0,603	1,23
8,39	0,084	0,705	1,23
8,31	0,108	0,899	1,22
8,23	0,130	1,066	1,21
8,19	0,144	1,183	1,21
8,12	0,160	1,299	1,20
7,97	0,195	1,557	1,18
8,24	0,210	1,730	1,23
8,14	0,250	2,035	1,22
8,06	0,290	2,337	1,22
7,99	0,320	2,557	1,21
7,90	0,340	2,686	1,21
7,92	0,390	3,089	1,23
7,59	0,470	3,567	1,21
6,91	0,560	3,870	1,24
5,34	0,570	3,044	1,00

Example of the calculation of m

$$m = \frac{U}{N * Ur * \ln\left(\frac{Isc - I}{Is} + 1\right)}$$

$$U = (8.31 \pm 0.01)V \quad \text{and} \quad I = (0.108 \pm 0.001)A$$

$$m = \frac{8.31}{15 * 25.7 * 10^{-3} * \ln\left(\frac{0.57 - 0.108}{10^{-8}} + 1\right)} = 1.2214$$

Calculation of the error

$$m_{min} = \frac{8.30}{15 * 25.7 * 10^{-3} * \ln\left(\frac{0.571-0.107}{10^{-8}} + 1\right)} = 1.2197$$

$$m_{max} = \frac{8.32}{15 * 25.7 * 10^{-3} * \ln\left(\frac{0.569-0.109}{10^{-8}} + 1\right)} = 1.2232$$

$$error = \frac{1.2232 - 1.2197}{2} = 0.00175$$

$$m = 1.2214 \pm 0.00175$$

The errors have been made by various causes. The first ones are the errors on the measuring devices. Another cause is the fact that the solar panel went during the measurements. This makes that the values deviate from the real values.

Out of these values, the average value of the diode factor was determined.

$$m_{avg} = 1.23$$

The new solar panel the coaches gave us has an N-value of 16 instead of 15. Because of this chance, the m-value became 1.15. In the next calculations, we make use of the first value, namely 1.23.

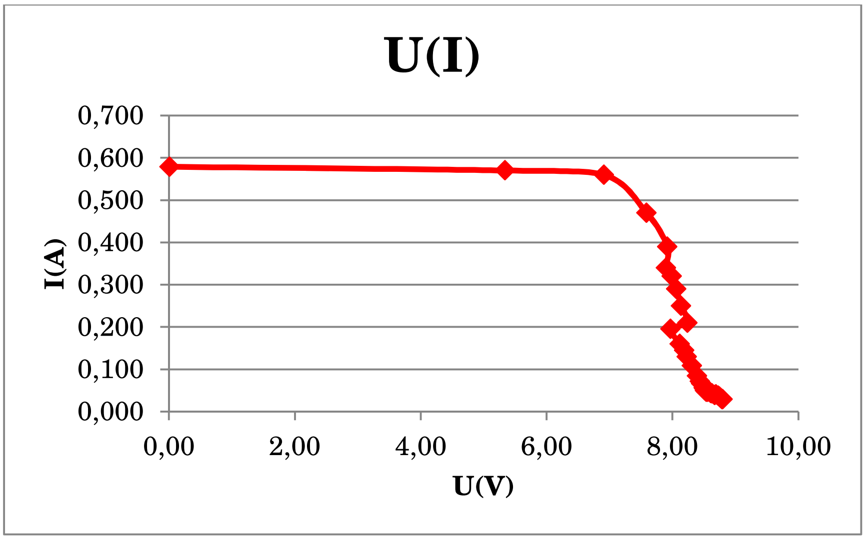


Figure 1: U(I) graph of the solar panel

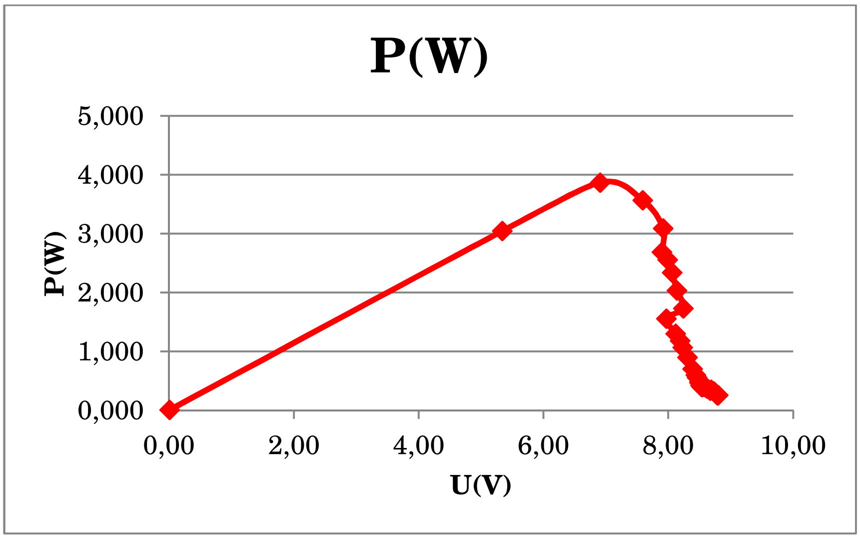


Figure 2: P(W) graph of the solar panel

The U(I) graph

The value of the current stays approximately the same and the voltage rises, until the breaking point where the voltage stays the same and the current declines. This graph is a good estimation of the real graph.

The U(P) graph

The U(P) graph is approximately the graph that we had to become. The power rises until the highest value. After this point, the power declines steep.

By checking these graphs, you can see that a lot of points are not in the expected line. To solve this problem, we calculate the voltage with the average value of m.

$$U = m * N * Ur * \ln\left(\frac{Isc - I}{Is} + 1\right)$$

Table 2: Calculated values with m=1.23

V(V)	I(A)	P(W)
8,45	0,029	0,245
8,45	0,029	0,243
8,45	0,032	0,270
8,45	0,035	0,293
8,44	0,037	0,314
8,44	0,040	0,341
8,44	0,039	0,328
8,44	0,042	0,356
8,44	0,044	0,368
8,44	0,047	0,396
8,44	0,048	0,401
8,44	0,047	0,394
8,44	0,046	0,390
8,43	0,050	0,419
8,43	0,054	0,457
8,43	0,056	0,474
8,42	0,066	0,556
8,41	0,071	0,601
8,40	0,084	0,706
8,38	0,108	0,907
8,36	0,130	1,082
8,34	0,144	1,204
8,32	0,160	1,332
8,28	0,195	1,618
8,26	0,210	1,735
8,21	0,250	2,052
8,15	0,290	2,363
8,10	0,320	2,591
8,06	0,340	2,740
7,95	0,390	3,099
7,69	0,470	3,613
6,88	0,560	3,853
6,55	0,570	3,734
0,01	0,579	0,006

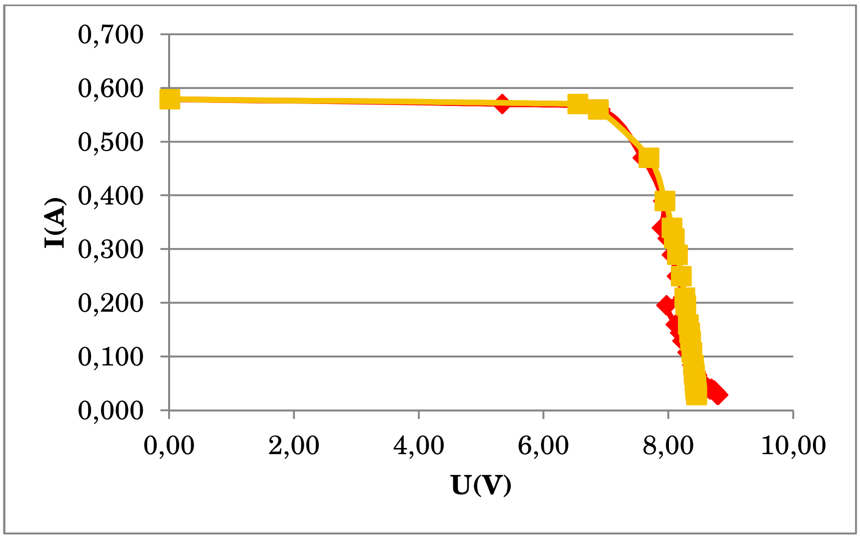


Figure 3: U(I) graph with m=1.23

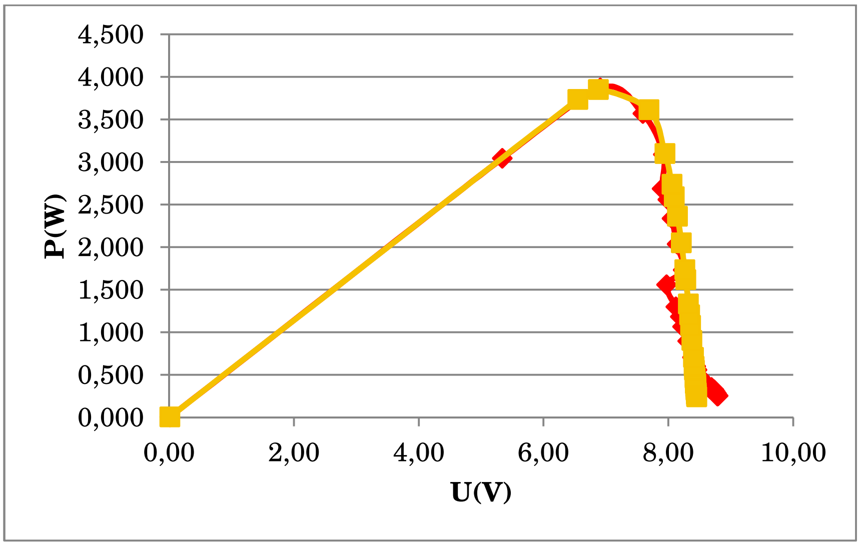


Figure 4: U(P) graph with m=1.23

When we combine the solar panel and the motor, we can look for the best working point. For the motor the formula is $U = I * R + \frac{n}{1120}$. The value of R can we find in the characteristics of the motor. R has a value of 3.32Ω. For the solar panel we use the next formula.

$$U = m * N * Ur * \ln\left(\frac{Isc - I}{Is} + 1\right)$$

Table 3: Values of U(V) by different n

0rpm	1000 rpm	2000 rpm	3000 rpm	4000 rpm	5000 rpm	6000 rpm	7000 rpm
U (V)	U (V)	U (V)	U (V)	U (V)	U (V)	U (V)	U (V)
0,096	0,989	1,882	2,775	3,668	4,561	5,453	6,346
0,096	0,988	1,881	2,774	3,667	4,560	5,453	6,346
0,106	0,999	1,892	2,785	3,678	4,571	5,463	6,356
0,115	1,008	1,901	2,794	3,687	4,579	5,472	6,365
0,124	1,016	1,909	2,802	3,695	4,588	5,481	6,374
0,134	1,027	1,920	2,813	3,706	4,598	5,491	6,384
0,129	1,022	1,915	2,807	3,700	4,593	5,486	6,379
0,140	1,033	1,926	2,819	3,712	4,604	5,497	6,390
0,145	1,038	1,930	2,823	3,716	4,609	5,502	6,395
0,156	1,049	1,942	2,835	3,727	4,620	5,513	6,406
0,158	1,051	1,943	2,836	3,729	4,622	5,515	6,408
0,155	1,048	1,941	2,834	3,726	4,619	5,512	6,405
0,153	1,046	1,939	2,832	3,725	4,618	5,511	6,403
0,165	1,058	1,951	2,844	3,736	4,629	5,522	6,415
0,180	1,073	1,966	2,859	3,751	4,644	5,537	6,430
0,187	1,080	1,973	2,865	3,758	4,651	5,544	6,437
0,219	1,112	2,005	2,898	3,791	4,683	5,576	6,469
0,237	1,130	2,023	2,916	3,808	4,701	5,594	6,487
0,279	1,172	2,065	2,957	3,850	4,743	5,636	6,529
0,359	1,252	2,145	3,038	3,931	4,824	5,716	6,609
0,430	1,323	2,216	3,109	4,001	4,894	5,787	6,680
0,479	1,372	2,265	3,158	4,051	4,944	5,837	6,729
0,531	1,424	2,317	3,210	4,103	4,995	5,888	6,781
0,649	1,542	2,434	3,327	4,220	5,113	6,006	6,899
0,697	1,590	2,483	3,376	4,269	5,161	6,054	6,947
0,830	1,723	2,616	3,509	4,401	5,294	6,187	7,080
0,963	1,856	2,749	3,641	4,534	5,427	6,320	7,213
1,062	1,955	2,848	3,741	4,634	5,527	6,420	7,312
1,129	2,022	2,915	3,807	4,700	5,593	6,486	7,379
1,295	2,188	3,081	3,973	4,866	5,759	6,652	7,545
1,560	2,453	3,346	4,239	5,132	6,025	6,918	7,810
1,859	2,752	3,645	4,538	5,431	6,323	7,216	8,109
1,892	2,785	3,678	4,571	5,464	6,357	7,250	8,142
1,922	2,815	3,708	4,601	5,494	6,387	7,279	8,172

Placing all the values in a graph, we find the optimal value for the rotational speed n. This is the point where the power is as high as possible. From the figure below, the optimal value for the rotational speed n is situated between 5000 rpm and 6000 rpm.

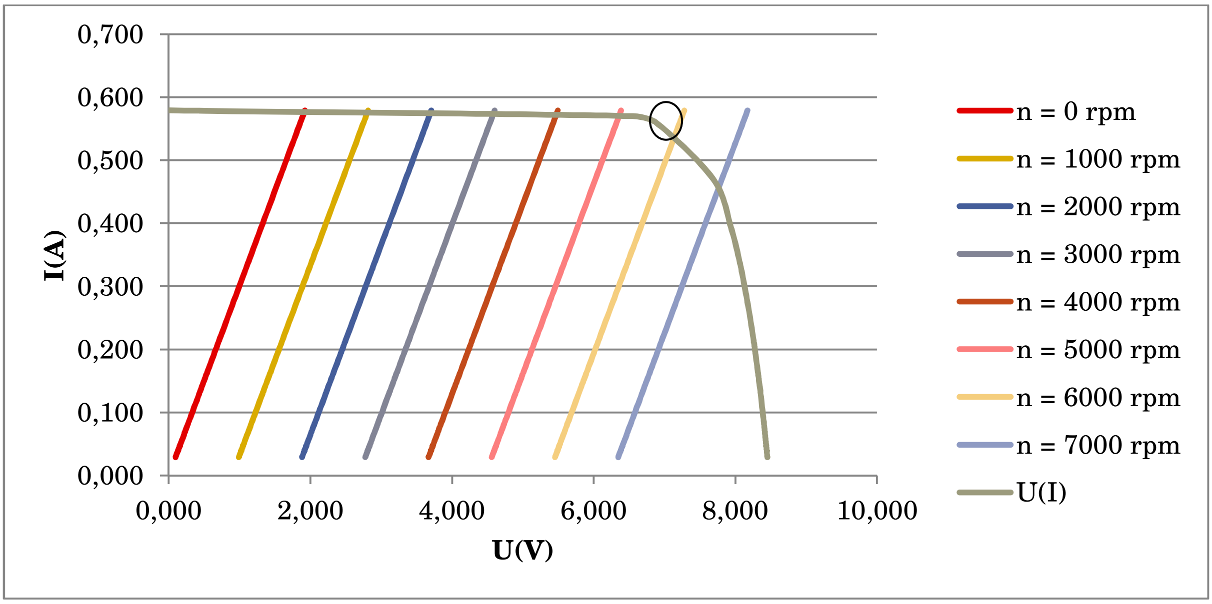


Figure 5: Graph to find working points

The maximum power is by U = 6.88V and I = 0.560A. With this values we can calculate the optimal rotational speed.

$$n = (U - I * R) * 1120$$

$$n = (6.88 - 0.560 * 3.32) * 1120 = 5623 rpm$$

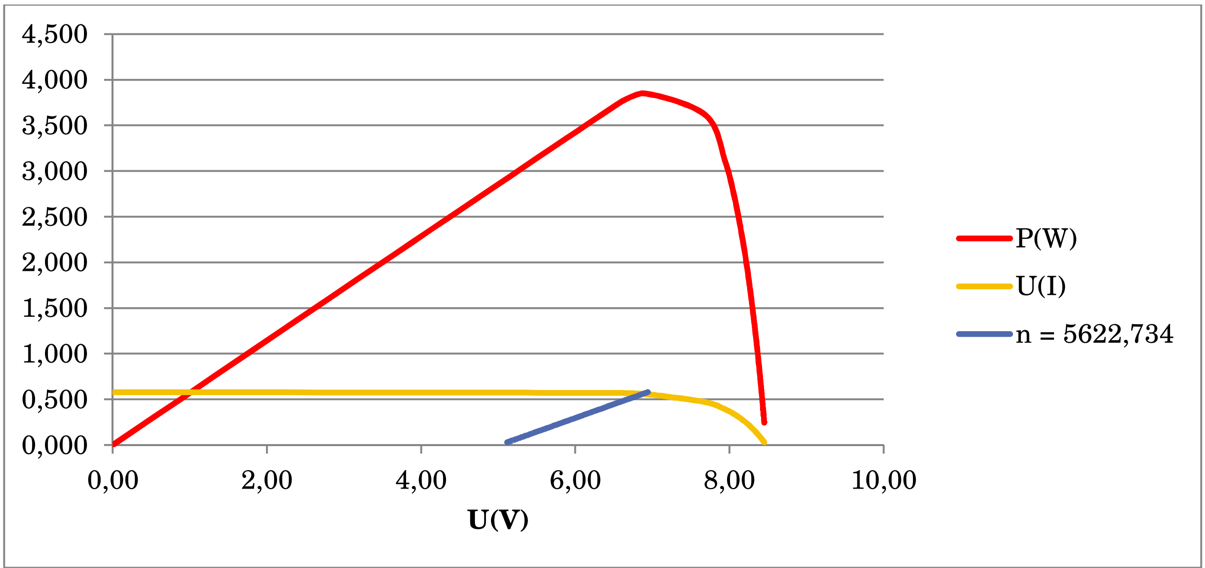


Figure 6: Graph with power, voltage and best rpm

1.1.2 Optimal ratio between the DC motor and the wheel

Introduction

First we calculated the K-value and from this value it is possible to find the gear ratio i. Secondly there is the Matlab simulation to precise our ratio.

1.1.2.1 Calculation

Start with the energy balance of the SSV:

$$E_{input} = \int F * dx = Ekin + Epot + (Fw + Fr) * x$$

From this energy balance, the K-value of the SSV will be calculated.
The K-value represents a ratio between the gear ratio and the radius of the wheel.
The K- value multiplied with the radius of the wheel of the SSV will give the gear ratio i.

Unit of the K-value = $\frac{1}{m}$

The Input Energy

The energy that will be delivered by the DC motor:

$$E_{input} = K * T * x * \eta$$

$K = the\ K - value$

$T = K(t) * Ia = 8.55 * 10^{-3} \frac{Nm}{A} * 0{,}57A = 4.87 * 10^{-3} Nm\ with\ K(t) =\ torque\ constant$

$x = the\ distance\ [m] = 14m$

$\eta = efficiency\ of\ the\ motor = 84\%$

$$E_{input} = K * 4.87 * 10^{-3} Nm * 14m * 0.84 = 0.057 * K\ [J]$$

The potential energy

$\mathrm{E_{pot} = m * g * h}$

$\mathrm{m = mass\ [kg]}$

$\mathrm{g = gravitation\ speed}\ \left[\frac{\mathrm{m}}{\mathrm{s}^2}\right]$

$\mathrm{h = height\ [m]}$

$$E(pot) = 0{,}886\ kg * 9{,}81\ \frac{m}{s^2} * 0{,}5m = 4{,}35\ J$$

$$[kg] * \left[\frac{m}{s^2}\right] * [m] = \frac{kg * m^2}{s^2} = [J]$$

The kinetic energy

$$E_{kin} = \frac{m * v^2}{2}$$

$$V = \frac{\omega}{K}$$

$$\omega = \frac{P}{T} = \frac{5W}{4.87 * 10^{-8} Nm} = 1027 \frac{rad}{s}$$

$$\text{Ekin} = \frac{m * \omega^2}{2 * K^2} = \frac{0{,}886 kg * 1027^2 \left(\frac{rad}{s}\right)^2}{2 * K^2} = \frac{466966{,}6}{K^2} \text{ J}$$

v = velocity car [m/s]
ω = angle frequency motor [rad/s]
P = power motor [W] = 5W (data sheet)

Air resistance

$$Fw = \frac{1}{2} * Cw * A * \rho * v^2$$

$$Fw = \frac{\frac{1}{2} * 0{,}5 * 0{,}03 m^2 * 1{,}293 \frac{kg}{m^3} * 1027^2 \frac{rad}{s}}{K^2} = \frac{10228.23}{K} N$$

$$[Fw] = m^2 * \frac{kg}{m^3} * \frac{m^2}{s^2} = \frac{m * kg}{s^2}$$

Cw = drag coefficient (dimensionless) = 0.5
A = frontal surface area [m^2] = 0,03 m^2
ρ = density of air [$\frac{kg}{m^3}$] = 1,293 $\frac{kg}{m^3}$
v = $\frac{\omega}{K}$ = (speed of the car) [$\frac{m}{s}$] = $\frac{1027 \frac{rad}{s}}{K}$ (see above)

Rolling resistance

Rolling Resistance Force = Rolling Resistance Coefficient * Normal Force

$$\text{Fr} = \text{Crr} * \text{N}$$

$$\text{Fr} = 0{,}012 * 8{,}62 \text{ N} = 0{,}10348 \text{ N}$$

Crr = rolling resistance coefficient = 0,012
N = Normal force = m*g*cos(α) = 0,886kg * 9,81 m/s² * cos(7,18°) = 8,62 N

Transmission ratio

E (input) = $\int F * dx$ = E kin + E pot + (Fw + Fr) * x

0,057 *K J= $\frac{466966{,}6}{K^2}$ J + 4,35 J + ($\frac{10228{,}23}{K^2}$ N + 0,10348 N) * 14m

Now we have a cubic equation with variable K. If we put it in Maple and search the K-value we get:

$$> \quad a := 0 = -0.057 \cdot K + \frac{466966.6}{K^2} + 4.35 + \left(\frac{10228.23}{K^2} + 0.10348\right) \cdot 14$$

$$a := 0 = -0.057\, K + \frac{6.1016\ 10^5}{K^2} + 5.7987$$

$> \quad solve(a, K)$

$$260.04,\ -79.153 + 186.82\, I,\ -79.153 - 186.82\, I$$

⇨ K= 260,04/m

Radius of the wheel = ra= 0,055 m

Gear ratio = i = Number of teeth on driven gear/ Number of teeth on driving gear

i = K * ra = 260,04/m * 0,055m = 14,3 ≈ 14

By calculation we find an optimal gear ratio of 14. By using Matlab we can probably find an even better value than the calculated 14.

1.1.2.2 Matlab Simulation

Because of problems with our previous program energy_func.m (Error using Energy_func (line 41)) we couldn't determine a second simulation with the proper parameters. We discussed this in team and used the first simulation again in this report.

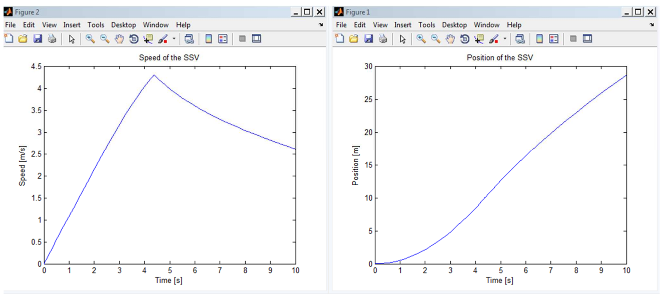
The Matlab simulation can give an idea of which value is the best optimal gear ratio. Matlab gives us, after filling in the parameters for our SSV and changing only the gear ratio, two graphs: the position and speed graph. We simulated for different gear ratios between 8 till 19.

Parameters:

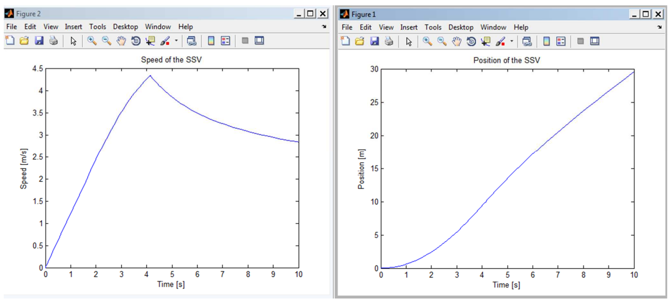
```
% set the parameters
% solar panel
Isc=0.88;
Is=1e-8;
Ur= 0.0257;
m=  1.231 ;
N= 15;
% DC-motor
R= 3.32  ;
Ce= 8.9285e-4 ;
% slope
g= 9.81;
a= 0.1253  ; % radians
% air resistance
Cw=  0.5  ;
A= 0.02  ;
p= 1.293  ; % density of air
% rolling resistance
Crr= 0.012  ;
% SSV
M= 1 ; % mass [kg]
r= 0.05 ;  % wheel radius [m]
ratio=  14 ; % gear ratio
```

Figure 7: Matlab parameters

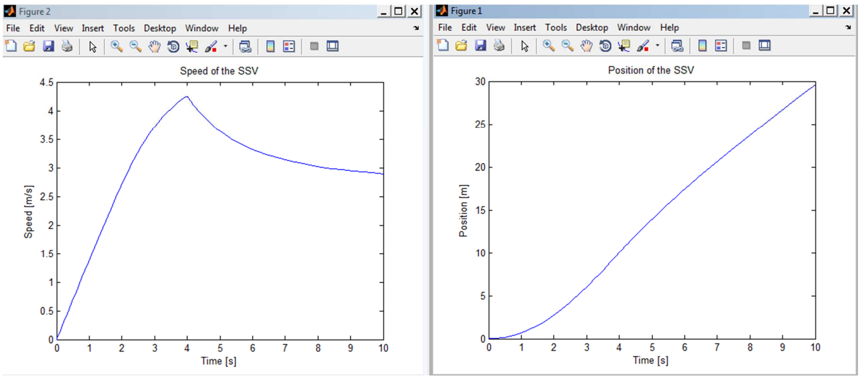
Gear ratio 8:



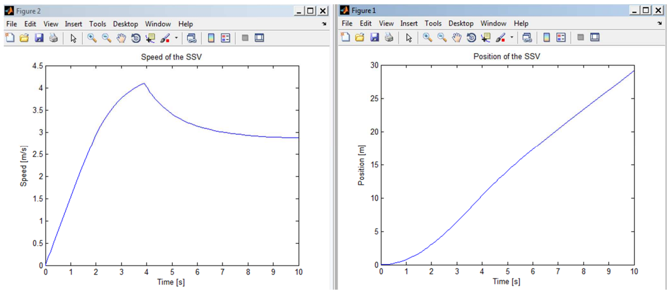
Gear ratio 9:



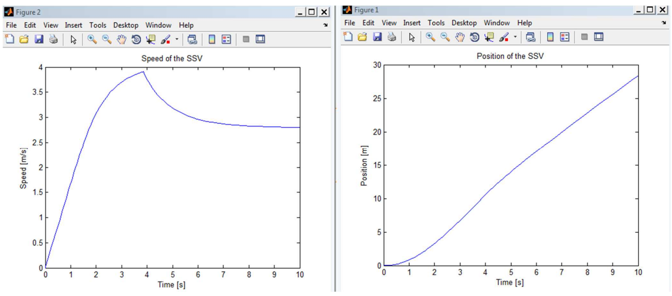
Gear ratio 10:



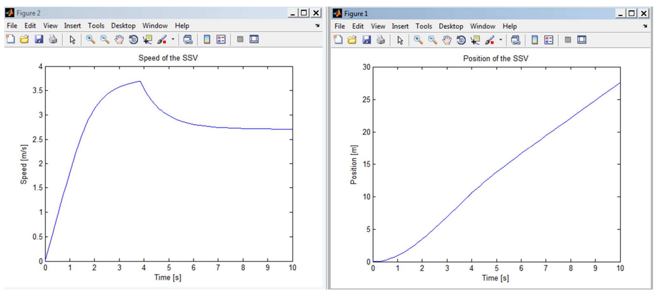
Gear ratio 11:



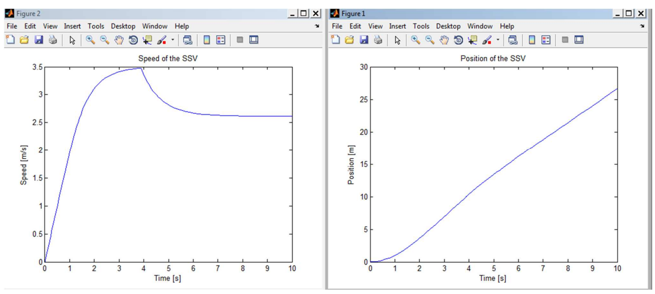
Gear ratio 12:



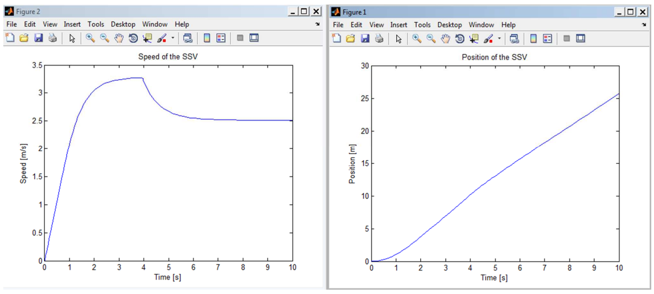
Gear ratio 13:



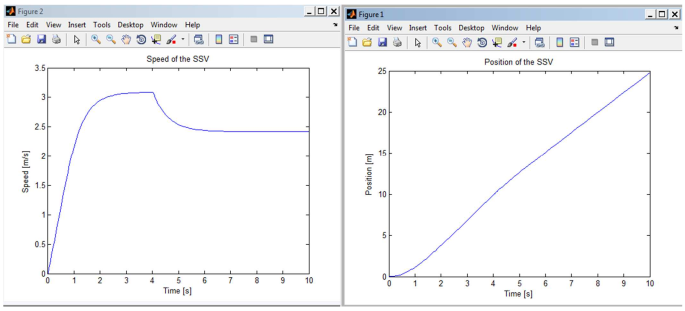
Gear ratio 14:



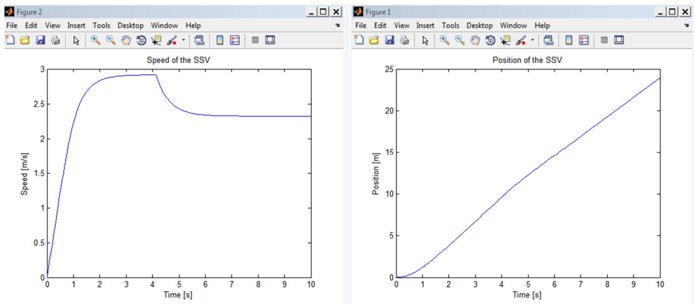
Gear ratio 15:



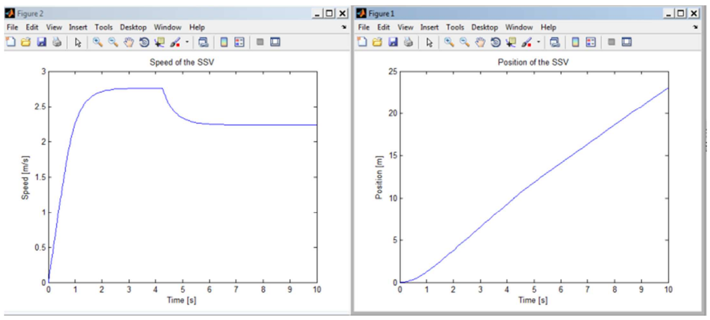
Gear ratio 16:



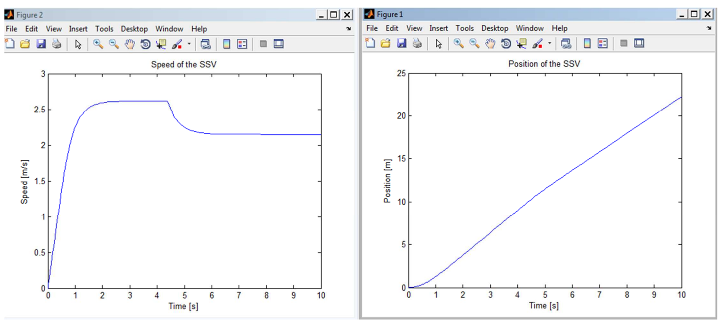
Gear ratio 17:



Gear ratio 18:



Gear ratio 19:



From the simulation in Matlab we can see that a gear ratio of 10 will give the highest speed of 4m/s after 4 seconds. If we choose a gear ratio of 14, the maximum velocity will be 3,5m/s after 4 seconds. There is a difference of 0,5m/s between the two. For the further simulation we will choose a gear ratio of 10.

1.1.2.3 Conclusion

The value we found in the Matlab simulation is not the same as our calculated value. By calculation we found an optimal gear ratio of 14, by simulation we selected an optimal gear ratio of 10. From now on we will use an optimal gear ratio of 10.

1.1.3 Design SSV

In this part we will describe the design of the SSV. We will explain in which steps our solar car was developed and made, which material we used and explain the reason why we used it, to eventually create our current design at which we are all quite fond off. In total we made two cars. We tested our first prototype and deleted our disadvantages to create our current solar car.

At the beginning of our project, we stated that we were going to focus ourselves on the appearance and structure of our car instead on focussing on innovative and technological parts. We can say we succeed in our main goal because we got a lot of support from the jury whom voted our SSV as the car with the third best design.

1.1.3.1 Basic design

Because we were aiming at design, we didn't really take the weight as a crucial factor in the beginning of the project. Our first SSV was shaped like a rowing boat or the backside of an iron displayed on the picture below. It had in total four wheels with-rear-wheel drive.

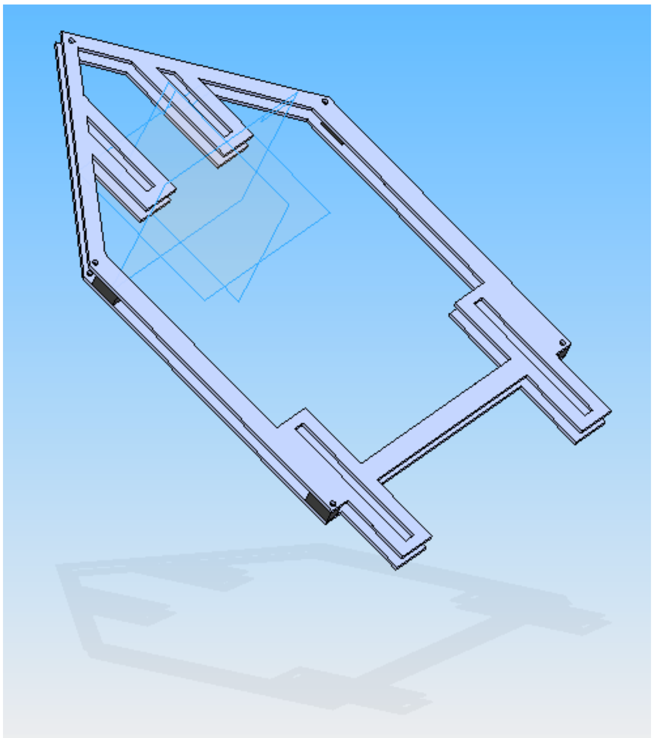


Figure 8: Shape of the SSV

In figure 8 you can see we chose for a double-layered structure to create a case for our internal components like the motor and the axes. This structure allows spreading physical loads more efficiently across the whole frame and allows us to align our components more easily.

We chose to not implement any form of steering. Doing so, we had to take in account the possibility of a collision. The idea behind the shape of an iron is that when the SSV collides with the sidewall, it would bounce itself back into the right direction. To reduce energy losses during and after impact we installed horizontal guiding wheels on the frame. When the car drives against the wall it will lose some of his velocity, but with the shape of the frame and the guiding wheels it will not come to a hold. The idea is that the car would slow down, but still be able to keep on going to finish the race.

The framework or body of the SSV is the most important structure. All the other components of the car are attached to it and therefore it is important that it's rigid enough to support and resists all the physical stress that works in on it. The first stress that works on the framework is of course the weight of the solar panel and DC motor. Other more severe types of stress can be obtained during collision at high speed. The frame has to be designed so that it can cope with constant stress of the solar panel and motor plus the stress during a possible collision. But next to these strength and endurance, the material also had to be available, cheap and manipulable.

These are the reasons why we preferred PMMA or Plexiglas. PMMA is a strong and lightweight material and can be cut by a laser cutter and still has good impact strength. The material has a density of 1.17–1.20 g/cm^3 and therefore has a good strength-weight ratio for our application. The biggest disadvantage is its brittleness, which makes it difficult to make changes in the design without cracking it. We chose not to paint our frame. The main reason why we didn't is because we wanted to keep our SSV as cold as possible because solar cells get less efficient when they are working in warm environments.

We chose to make as much as we can by our own. Therefore parts like the wheels, the gears and the supports were all made out of PMMA. But these structures are critical because they our constantly exposed to outside stresses.

1.1.3.2 Advanced design

In a next step we made internal adjustments to reinforce our structure and to make room for our motor block and our gears. Another big change is the installation of the front wheels. We were able to make our front wheels much smaller without having to change our original and calculated back wheels. We did this by making a special part that slides onto our frame and sticks out in the front. We inserted our bearings directly into these pieces to increase the fine-tuning of the front wheels so that they are aligned with the SSV. Another big advantage is that it was possible to set the wheels further out of each other, which increased drastically the stability of the whole SSV. All these changes are displayed in the following two pictures.

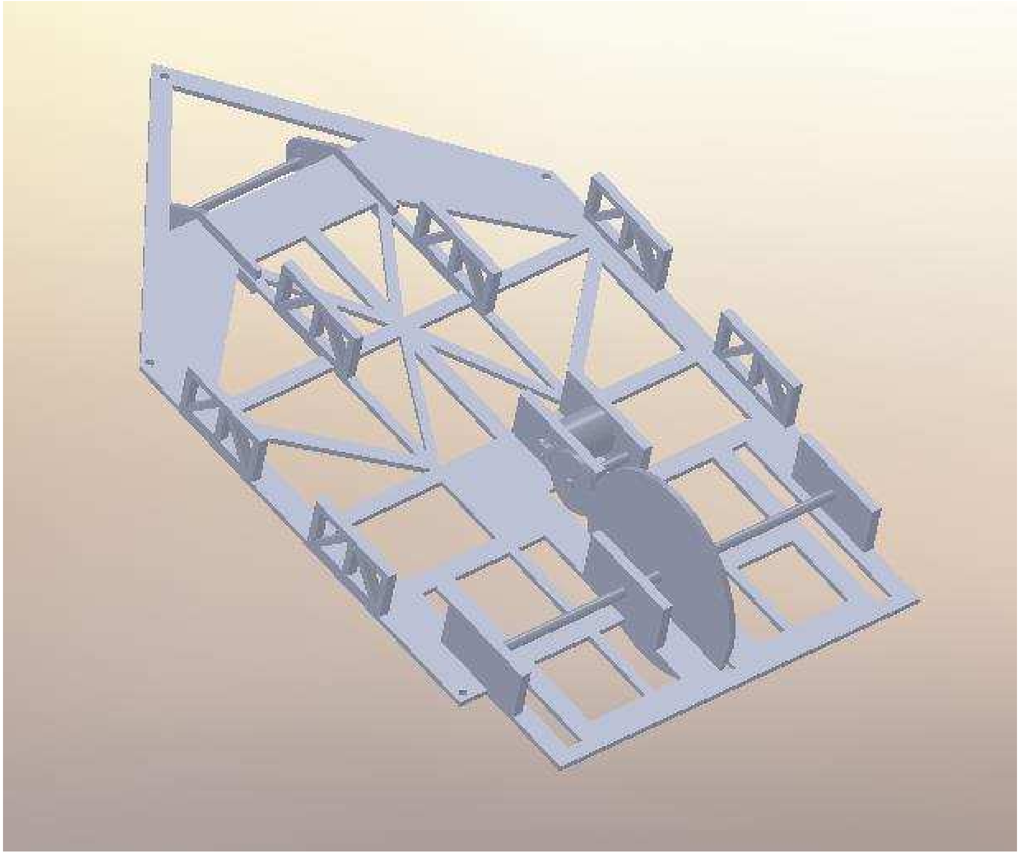


Figure 9: First design of the SSV (only the underside)

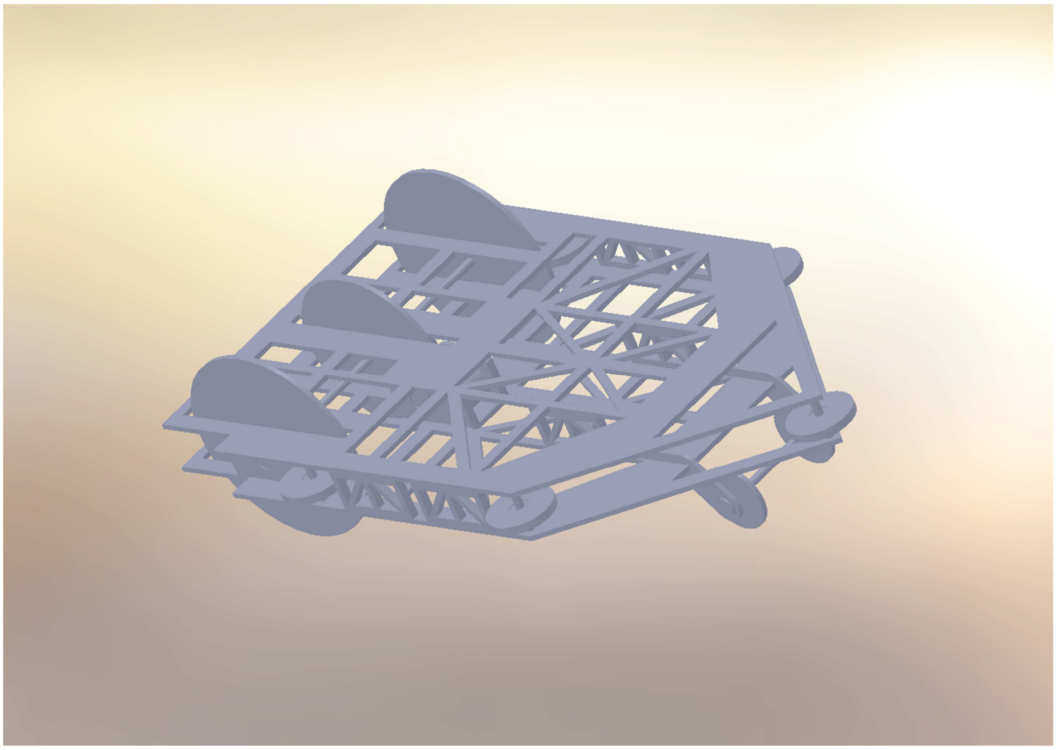


Figure 10: The first version of the SSV

This is the first car that we actually made in Fablab with the laser cutter for the upcoming test run. Therefore some parts will be explained even more in detail.

Shape:

As stated in the beginning the shape of the frame will be comparable to that of a two layered iron. It will have a small snout at the front and it widens out near the end of the frame. This will make the car bounce in the right direction again after it collides with the wall. It is not as wide as the solar panel, but because the guiding wheels stick out of the design, the solar panel will be protected at all time. Our panel will be placed at an angle of 32 degrees. This is an average value to get as much sun as possible during the race. This also means that are car doesn't have to be as long as the solar panel. Due to the solar panel it is hard to obtain a good aerodynamic flow around the car, so we tried to make it as good as possible by position of the panel. It is possible to make a better casing with for example fiberglass, but this makes our SSV weigh even more than it already would. The weight of the SSV is still more important than the air friction, because it won’t reach high speeds. The two layers of our chassis are both 3mm Plexiglas.

Solar panel:

To deliver the required power for our motor, we used a solar panel by Soltech. We opted for a fixed installation of our panel, with the big disadvantage that we wouldn't get enough sunlight during the race. To compromise, we have placed our panel at an angle of 32 degrees so, which meant that if we raced towards the sun, we would get enough incoming sunlight. In the race regulations is located the positioning of the track which was indeed oriented to the sun. The panel will rest on the front of the frame and will be held up at the back by an extension at the end of the frame. This will be made out of 5mm Plexiglas, and will therefore weigh a lot. The solar panel and its supports were back then our biggest weight.

Driving force:

A Maxon DC motor transforms the delivered electrical power to the vital mechanical power to thrust the SSV towards the finish line. The motor is directly connected to the solar panel. The panel delivers the needed current to generate power. The rotation of the motor will be translated trough three gear wheels onto the rear-driving shaft. The ideal gear ratio is calculated and simulated in the first case report. Out of this information we opted for a gear ratio of 1:10. With this ratio we increase the torque, which is needed to accelerate, at the cost of fewer rotations per minute.

The DC motor was attached in the centre of the frame to make sure we didn't imbalance our SSV. The gears have to be fitted into the framework without weakening it and they had to be strong by themselves and had to be big enough to transfer the power. This main reason explains why we used 5mm PMMA for our gears. Three were necessary because we drew them ourselves. The smallest gear wasn't able to get a good grip on the biggest gear and therefore we had to implement another gear that was qua size in between the sizes of the two outer gears. All gears are made out of 5mm Plexiglas. We are aware that these gears will produce more friction instead of just buying them. The

first one is directly distorted on to the small axle of the motor and has a diameter of 10mm. The second one has a diameter of 30 mm and has a bearing inside so it is allowed to roll freely to transfer the power with the least amount of friction. The biggest gear is directly connected to the driving shaft and has a diameter of 100 mm. In total we reach our desired ratio 1:10 with right amount of teeth. With the implementation of a new gear, you have to take account the reversed rotation of the axes. But the rotational direction of the motor is easily changed by changing the motor's poles.

The driving shaft is the shaft on which the rotation of the motor in translated to. It is made out of steel, which endures the different torsions and other outside stresses. It has a diameter of 25 mm and we chose our bearings based on this value. It was important to ensure that the car would drive straight, therefore we put a lot of effort in aligning the wheels. The wheels had to be fixed on to the axle, so we supported the axle by three pieces Plexiglas that had the bearings inside. This improved the ability to align our car more fluently. The bearing holders are placed as close the wheels as possible. Otherwise the forces on the wheels could result in momentums on the shaft.

<u>Wheels:</u>

The wheels are all made out of 5mm PMMA to ensure we get enough traction on the rubber surface. The front wheels have a diameter of 25 mm

The rear wheels are much bigger than the front wheels because we opted for rear-wheel drive and we wanted to create enough torque to accelerate our heavy SSV. They have a diameter of 110 mm so that the gear would be lifted off the ground. A larger maximum speed is obtained by using a smaller radius, because of a constant angle speed = $r.\omega$. A downside is that larger wheels have larger inertia. We have to find a healthy equilibrium between all these factors. Therefore we chose a radius of 55 mm. To prevent our rear wheels from spinning uncontrolled at the start, we considered coating them with a type of rubber material.

The importance of the alignment is already explained, but not yet the installation of the wheels. We first made the hole for the shaft a little too small so we had to force them onto the axes by mechanical force and warmth deformation.

<u>Guiding wheels:</u>

To reduce friction when driving against a wall with the side of our SSV, we installed guiding wheels on the horizontal plane of the frame between the two layers. Two small wheels on each side of the SSV and one on the front will probably be enough to prevent form stopping after collision. The wheels of course have to be light weighted and evenly distributed at each side of the frame, therefore we opted for 3mm PMMA with a diameter of 40mm. We didn't insert bearings inside the guiding wheels, this would only increase the weight of the SSV, and the guiding wheels are there for a worst-case scenario.

Reinforcements:

The frame will need some reinforcements. The save weight some parts of the frame are cut out. There also has to be place for the gears to fit in the frame. It is important to check if the frame is still rigid enough, that was something we could test after building our prototype. For this version we chose for 5mm PMMA supports because we were not sure of it could carry the weight.

The rear wheels are larger than the front ones. The larger the radius, the larger the lower speed will be. This however creates a greater torque to accelerate the SSV. A larger maximum speed is obtained by using a smaller radius, because of a constant angle speed $= r.\omega$. A downside is that larger wheels have larger inertia. We have to find a healthy equilibrium between all these factors. Therefore we chose a radius of 5cm. To prevent our rear wheels from spinning uncontrolled at the start, we will coat them with a type of rubber material.

1.1.3.3 Test run

The day before the test run, we encountered many difficulties with the assembly of our SSV. It was at that moment when we actually saw the pieces in real life that we knew that adjustments were going to be necessary in a next version. Our SSV was bulky, it weight too much, and wasn't the real life image of what we had in mind. After some advice of the coach, we totally redesigned the whole SSV, but without losing elements we were all fond off, like the double-layered structure, or the front wheels holders. And the result was very pleasing...

1.1.3.4 Final design

We had to find ways to compensate our disadvantages and had to change our main goal a little bit. The design was still a priority, but the car would still have to be efficient. Therefore we made lots of changes that resulted in our current SSV, which is displayed in the following picture.

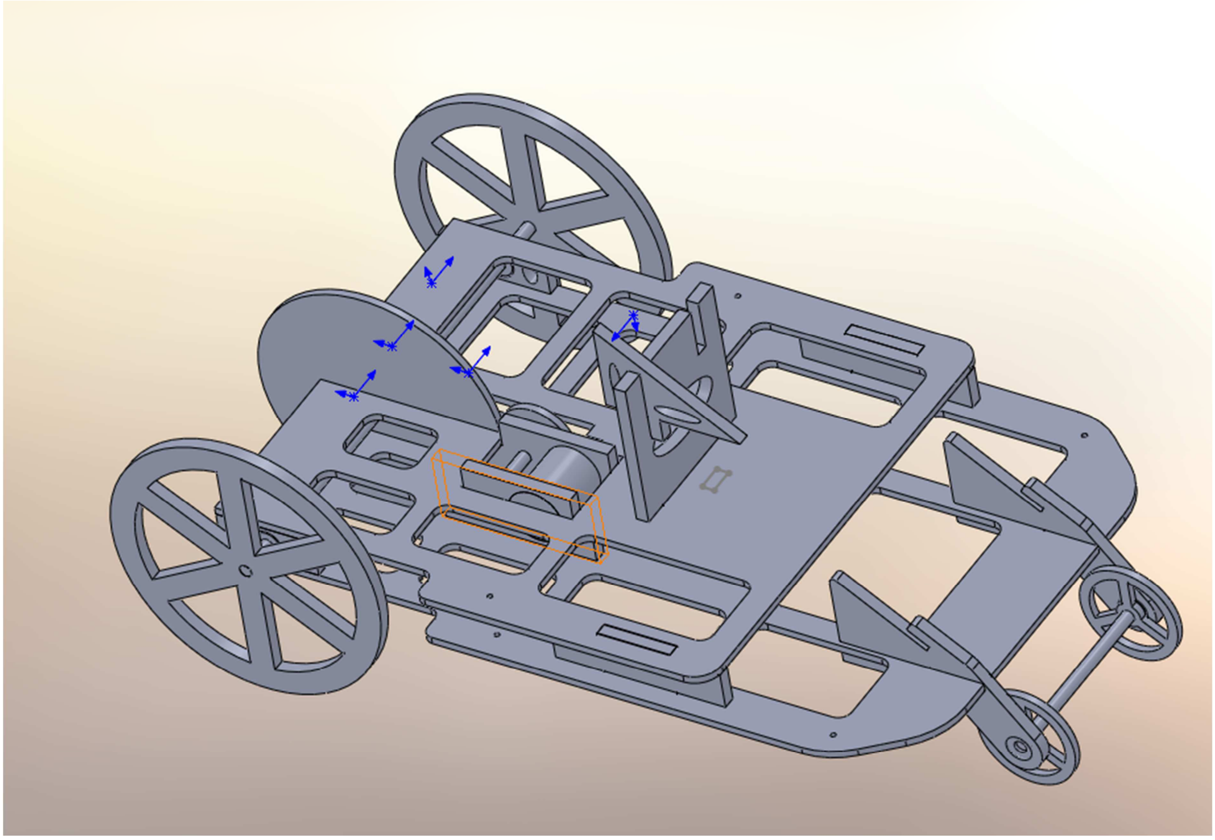


Figure 11: The final version of the SSV

Here is a summation of all the structural changes that we performed:

- We kept our main structure but lowered it, so that there isn't as much space as before. In our first design the whole motor was inside a shell, but now it sticks out a little bit out of the chassis. This makes it easier to access the motor in case of difficulties and supports the chassis in the middle.

- The frame plates aren't identical anymore. By making the above one, smaller, it was possible to lower our solar panel which had the advantage of lowering the mass center of our SSV and reducing both friction and air drag.

- The nose of the frame is gone. We did this because of the width of the track. We assume our car would never collide in such a big angle so that the nose was unnecessary weight.

- The whole frame is more feminine, more rounder which decreases the tensions in the whole SSV.
- We based our first design on a wrong solar panel. The new solar panel was longer but less wide. So we were able to make our SSV also less wide.

- The supports are made longer, but we used less weight, because there weren't as many as before. Also the supports are able to click inside the frame so that we can align our frame with the same precision as the laser cutter.

- The backside of the SSV is open, this results in a certain loss of weight but it makes it possible to absorb more stresses due to the leaf spring effect of the material. Both driving wheels are therefore able to absorb different shocks more efficiently.

- The wheels aren't captured inside the frame, which again ensures a weight loss, but it makes the installation of the wheels much easier.

- We made bigger slots for the gears to increase the ease of installation.

- We only used two bearing supports for the main axle instead of three, which reduces the internal friction losses.

- We combined the front part of the panel holder and the parts that hold the front wheels.

- We made a new back support for the panel, which was just a third of the weight of the previous bulky supports. This part goes through both chassis the get more stability and support in different spots.

- We chose not to use a rubber coating on the wheels because we had enough traction and it would only increase drag forces.

- Instead of using five guiding wheels we are only using four. The two in the front are fixed onto the frame by using small bolts and screws. The two in the back are forced on nails, which can move freely.

- We inserted a switch mechanism so it was easier to operate the solar car.

All these changes led to our current SSV: the real Louis XIV that has won the third design prize.

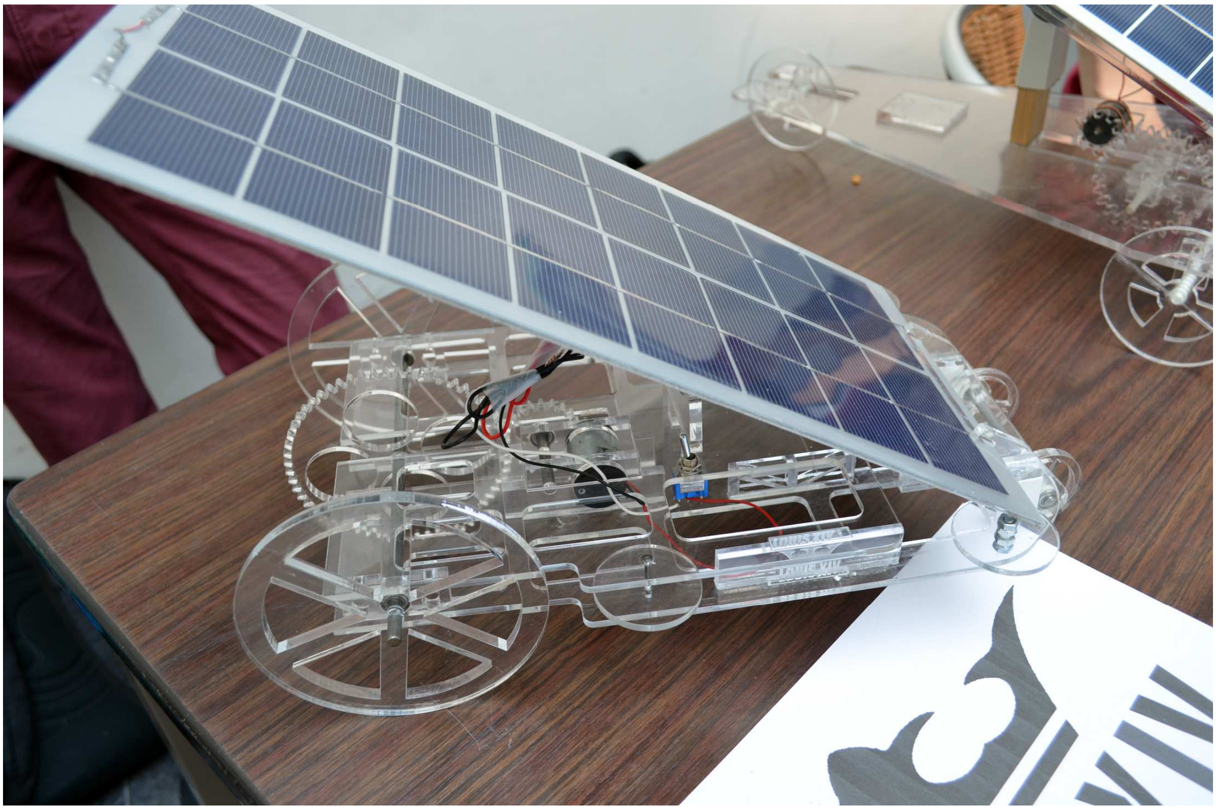


Figure 12: Photo of the real SSV

1.1.4 Bisection method

In this chapter the displacement and the velocity of the car during the first second of the race will be determined with numerical methods. They both will be calculated in two different situations. In the first situation we will use an interval of 0,1 seconds, in the second situation we will use an interval of 0,2 seconds with the assumption that the acceleration is constant during that time interval. At the end of the chapter we will discuss the results.

If we take the solar car as the system, than we have several kind of energies that involve the behaviour. We have to take into account the kinetic energy, the potential energy, the dissipated power and the work input.

$$Ekin = \frac{1}{2} * M * v(t)^2$$
$$Epot = M * g * \sin(\alpha)\, s(t)$$
$$Pdis = M * g * Crr * \cos(\alpha)\, v(t) + \frac{1}{2} Cw * A * \rho * v(t)^3$$
$$Win = E(t) i(t) dt$$

Due to the unbalance between dissipated and input energies, the solar car does not conserve energy. A reasonable approach for the energy function can be derived from Newton's second law:

$$a(t) = g * (\sin(\alpha) - \cos(\alpha)\, Crr) + \frac{20 * I * Ce\Phi t}{M * \Pi * r} - \frac{1}{2} \frac{Cw * A * \rho * v(t)^2}{M}$$

Due to the fact that

$$v(t) = \frac{d}{dt}s(t)$$

$$a(t) = \frac{d}{dt}v(t)$$

$$a(t) = \frac{d^2}{dt^2}s(t)$$

We can say that the above equation is a second order differential equation.
We have two constraints:

$$E(t) = Ke\omega = \frac{30 * CE\Phi * v(t) * gearratio}{\Pi * r}$$

$$i(t) = isc - is\left(e^{\frac{U(t)}{m*N*Ur}}\right) - 1$$

We begin our calculations with the following parameters for the solar car:

$\alpha = 7.18°$
$g = 9.81\frac{N}{kg}$
$Crr = 0.012$
$CE.\Phi = 8.9285 \text{ x } 10^{-4}\frac{V}{rpm}$
$r = 0.04m;\ \pi = 3.14$
$M = 1kg$
$Cw = 0.5$
$A = 0.02$
$\rho = 1.293\frac{kg}{m^3}$

For the solar panel we have the current i(t):

$$i(t) = isc - is\left(e^{\frac{E(t)+i(t)R}{mNUr}}\right) - 1$$

With $Isc = 0.88A$; $Is = 1 * \frac{10^{-8}A}{m^2}$; $m = 1.1$; $N = 15$, $Ur = 0.0257V$; $Ra = 3.32\Omega$

The initial condition in both situations at t=0s is:

$$s(0) = 0$$
$$v(0) = 0$$
$$i(0) = 0.88$$

Interval 0,1

To calculate the displacement and speed at t=0,1s we need to know the acceleration in this time interval. To calculate the acceleration we need to know the current i(t). For the first interval we have the maximum current of 0,88A:

$$a(0) := 9.81\cdot(\sin(0) - \cos(0)\cdot 0.012) + 0.88\left(\frac{8.92857\cdot 10^{-4}\cdot 60\cdot 10}{1\cdot 2\cdot 3.14\cdot 0.05}\right) - 0.5\cdot 0.03\cdot 1.293\cdot\left(\frac{0}{2\cdot 1}\right)$$

$$a(0) := 1.383644637$$

With this value we can now calculate the displacement and speed at 0,1s:

$$v(0.1) := a(0)\cdot t1$$

$$v(0.1) := 0.1383644637$$

$$s(0.1) := v(0)\cdot t1 + \frac{a(0)\cdot t1^2}{2}$$

$$s(0.1) := 0.006918223185$$

For the next interval we need to calculate the current at t=0,1s. Due to the fact that the current from the solar panel is a function of its own function, called a recursive function, we use the bisection method to search for a root of f(x). We know that i(t) must between 0 and 0,88. We calculate the function value for A = 0,88 and B = 0 en become a positive and a negative value:

$$f(A1) := 0.88 - 0.88 + 10^{-8}\cdot\left(\exp\left(\frac{(E(0.1) + 0.88\cdot 3.32)}{1.231\cdot 15\cdot 0.0157}\right) - 1\right);$$

$$f(A1) := 0.0005375607418$$

$$f(B1) := 0 - 0.88 + 10^{-8}\cdot\left(\exp\left(\frac{(E(0.1) + 0\cdot 3.32)}{1.231\cdot 15\cdot 0.0157}\right) - 1\right)$$

$$f(B1) := -0.8799999874$$

Because the function is continuous, there must be a root within the interval [0;0,88].

In the first iteration, the end points of the interval which brackets the root are B = 0 and A = 0,88 so the midpoint is C = (0,88+0)/2 = 0,44. Now we calculate the function value for

$$f(C1) := 0.44 - 0.88 + 10^{-8}\cdot\left(\exp\left(\frac{(E(0.1) + 0.44\cdot 3.32)}{1.231\cdot 15\cdot 0.0157}\right) - 1\right)$$

$$f(C1) := -0.4399965263$$

the midpoint:

We see that the value is negative therefore B = 0 is replaced by B = 0,44 for the next iteration to ensure that f(A) and f(B) have opposite signs. As this continues, the interval between A and B will become increasingly smaller, converging on the root of the function. The values of the next intervals are gathered in the table below.

Table 4: Values of the bisection method

Iteration	A_n	B_n	C_n	$f(C_n)$
1	0,88	0	0,44	-0,43999
2	0,88	0,44	0,66	-0,21996
3	0,88	0,66	0,77	-0,10946
4	0,88	0,77	0,825	-0,05471
5	0,88	0,825	0,8525	-0,02711
6	0,88	0,8525	0,86625	-0,01329
7	0,88	0,86625	0,873125	-0,00638
8	0,88	0,873125	0,8765625	-0,00292
9	0,88	0,8765625	0,87828125	-0,00119
10	0,88	0,87828125	0,879140625	-0,00033
11	0,88	0,879140625	0,8795703125	0,000105

We can see in the table that the root of the function goes to 0,879. Now we have a value for i(t) in the second interval:

$$i(0.1) = 0.879$$

We use this in the formula for the acceleration:

$$a(0.1) := 9.81\cdot(\sin(0) - \cos(0)\cdot 0.012) + i(0.1)\left(\frac{8.92857\cdot 10^{-4}\cdot 60\cdot 10}{1\cdot 2\cdot 3.14\cdot 0.05}\right) - 0.5\cdot 0.02\cdot 1.293\cdot\left(\frac{v(0.1)^2}{2\cdot 1}\right)$$

$$a(0.1) := 0.7611562294$$

From this we can calculate the displacement and speed at t=0,2s:

$$v(0.2) := a(0.1)\cdot t2 + v(0.1)$$

$$v(0.2) := 0.2905957096$$

$$s(0.2) := v(0.1)\cdot t2 + \frac{a(0.1)\cdot(t2)^2}{2}$$

$$s(0.2) := 0.04289601733$$

The same calculations are done for the next intervals with the following result:

Table 5: Values of s(t), v(t), a(t) and i(t) per 0,1s

t (s)	s (m)	v (m/s)	a (m/s^2)	I (A)
0	0	0	1,383644637	0,8800
0,1	0,00691822	0,13836446	0,7611562294	0,8790
0,2	0,04289602	0,29059571	0,7607340575	0,8787
0,3	0,12141175	0,51881593	0,7557638054	0,8752
0,4	0,26798748	0,82112145	0,7349481606	0,8570
0,5	0,50242924	1,18859553	0,6618334491	0,7887
0,6	0,83228734	1,58695598	0,5270302907	0,6610
0,7	1,23910934	1,9546168	0,3734118049	0,5158
0,8	1,68318522	2,25334625	0,2379547300	0,3885
0,9	2,12438329	2,4675055	0,1367468442	0,2938
1	2,53587893	2,60425235	0,0707101129	0,2323

Interval 0,2

We use the same principle as in the previous situation. The only difference is that our intervals are longer. The results are in the table below:

Table 6: Values of s(t), v(t), a(t) and i(t) per 0,2s

t (s)	s (m)	v (m/s)	a (m/s^2)	I (A)
0	0	0	1,383644637	0,8800
0,2	0,02767289	0,27672893	0,760587846	0,8788
0,4	0,1715386	0,58096407	0,753365424	0,8733
0,6	0,3679914	1,03298332	0,700143939	0,8248
0,8	1,05043272	1,59309847	0,524153594	0,6583
1	1,85517527	2,11725207	0,300609049	0,4473

Discussion

If we combine the graphs of the two different intervals for the distance and speed, we can see that they differ from each other.

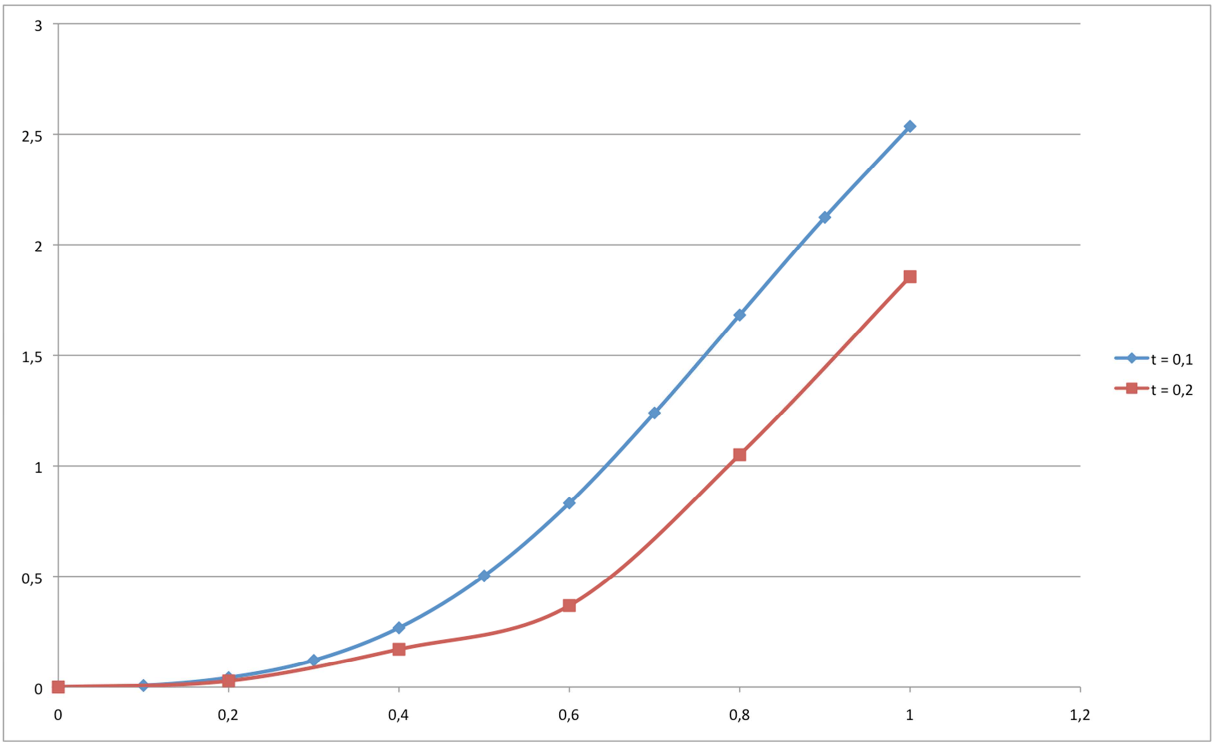


Figure 13: Comparison of the distance in function of time

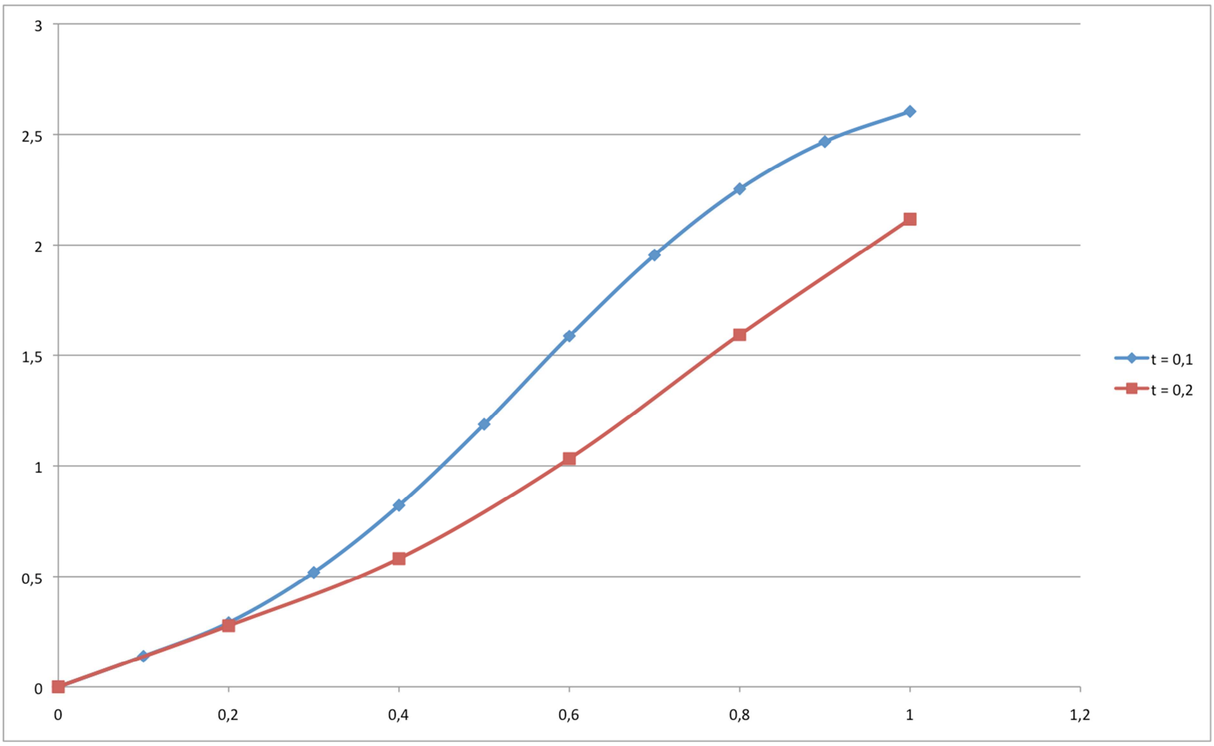


Figure 14: Comparison of the speed in function of time

The difference between the graphs is caused by the different time intervals by which they are evaluated. We assume a constant acceleration during each interval t(i). Doing so, we calculate the values during the next time interval t(i+1). Using this values the acceleration in the interval t(i+1) can be calculated. We assume a constant acceleration, but in practice the acceleration is far from constant. Because of this assumption the graph with the 0,1s interval is evaluated more frequently than the graph of the 0,2s interval. We can say that the graph of the 0,2s interval always lags the actual graph of the SSV. The 0,1s interval also lags the actual graph, but the values are evaluated more frequently and therefore this graph gives a more accurate approximation. The method that explains this all is called the "Euler method". The method is a first-order numerical procedure for solving ordinary differential equations with a given initial value.

1.1.5 Sankey diagram

A Sankey Diagram is a visual way of presenting the energy losses in the solar car. In each of the following cases, we assume that the power radiation of the sun is about 800 W/m². We are going to examine two different cases. At the moment that the SSV has travelled a distance of ten meters and when the SSV has reached his maximum velocity.

PS: These Sankey diagrams are not correct, due to assumptions and bad simulations. We recalculated all the values in "Case SSV Part two" of this process report.

First we are going to calculate the total power available and afterwards we are going to retract all the power losses. In each case we have 4 types of power losses: losses due to the solar panel, due to the motor, due to the transmission and due to resistances.

Total power available:

The solar panel contains 15 solar cells, which have a total surface of 0,03969m².

$$15 * (0{,}063\ m * 0{,}042\ m) = 0{,}03969\ m^2$$

The total power delivered by the sun on our solar panel is then 31,752 Watt and is the maximum power that the car can use during the race.

$800\ W/m^2 *\ 0{,}03936\ m^2 =\ 31{,}752\ Watt$

(We start with 31,752 Watt)

Power losses in the solar panel:

It is possible to calculate the Power losses because in the lab, we tested the solar panel to calculate its diode factor with a lamp of 300 Watt/m^2.

The incoming power is $0{,}03969\ m^2 * 300\ Watt/m^2 = 11{,}907\ Watt$. The maximum measured power was 3,3 Watt. The efficiency can be calculated with these two values: 27,71%.

The total power loss due to the solar panel is $(1 - 0{,}2771) * 31{,}752\ =\ 22{,}954\ Watt$.

(We have 31,752 - 22,954 = 8,798 Watt left)

Power losses in the motor:

In the data sheet it is stated that the maximum efficiency is 84%. This occurs when there is no load connected to the motor and the motor reaches his maximum rpm. The real efficiency will be lower, we assume it will be around 80%.

So only 80% of the power delivered by the solar panel is transformed in power for the acceleration:

$$0{,}8 * 8{,}798 = 7{,}038 \text{ Watt. We lose } 1{,}76 \text{ Watt.}$$

(We keep 8,798 - 1,76 = 7,038 Watt left)

Power losses in the transmission:

We do not have our gearbox yet, but we will test our gears experimentally to calculate the efficiency and the power losses in the transmission and the losses due to friction between the axes and chassis. We will do this by letting our SSV roll down a slope once with the gearbox installed and once without the gearbox installed. By calculating the ratio of the travelled distances we get the efficiency of our transmission. For now we assume it will be around 94% or a 2% loss for each gear. In total we lose 0,422 Watt.

$$7{,}038 * 0{,}06 = 0{,}422 \text{ Watt}$$

(We keep 7,038 - 0,422 = 6,616 Watt left)

All these losses have the same value for each of the following two cases because the speed is never a variable in the calculation for these losses.

1.1.5.1 Case 1: Sankey diagram at x = 10 meters.

$v(x = 10) = 5{,}7$ m/s

Overall applies, power is the product of the force and the speed or in symbols:

$$P = F * v$$

Power losses due to air drag:

$$F_{air\ drag} = \rho_{air} * A * C_w * \frac{v^2}{2}$$

With:

$\rho_{air} = 1{,}293\ kg/m^3$

$A = 0{,}02\ m^2$

$C_w = 0{,}5$

$v = 5{,}7\ m/s$

$$P_{air\ drag} = F_{air\ drag} * v$$

So: $P_{air\ drag} = 0{,}21$ Watt

Power losses due to friction:

$$F_{friction} = C_{rr} * N$$

With:

$C_{rr} = 0{,}012$

$N = m * g = 1 * 9{,}81 = 9{,}81\ N$

$$P_{friction} = F_{friction} * v$$

So: $P_{friction} = 0{,}671$ Watt

We have a total power loss $P = P_{air\ drag} + P_{friction} = 0{,}21 + 0{,}671 = 0{,}881$ Watt.

This is 2,77% of the power that was available.

The resting power is 5,753 Watt or 18,06%.

Sankey diagram

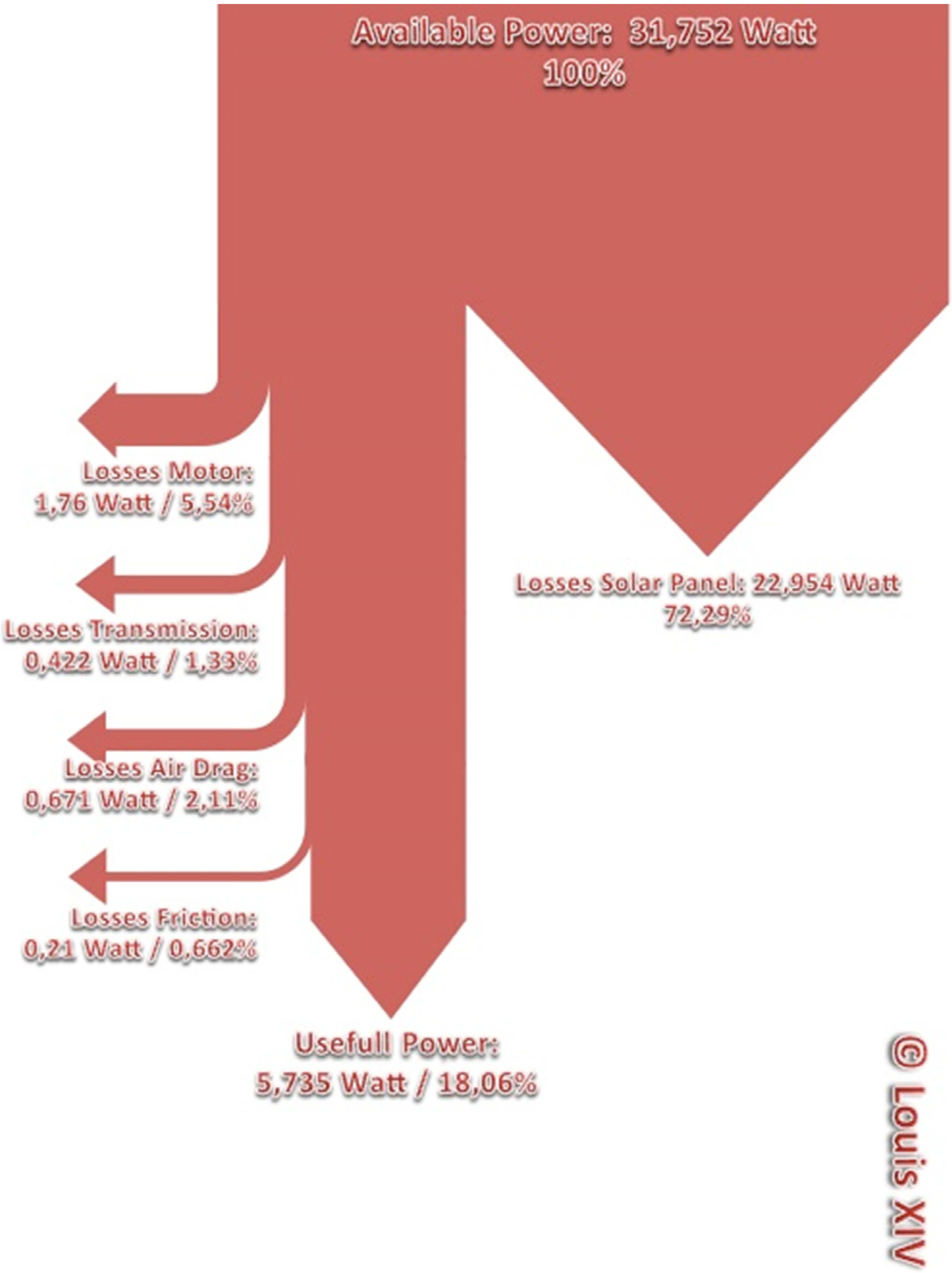


Figure 15: Sankey diagram at x=10m

1.1.5.2 Case 2: Sankey diagram at the top speed.

We can calculate our theoretical maximum speed, at this point, there is no power left to accelerate. This means that our output power is equal to our friction and air drag power losses during the race.

$$P\ (v_{max,out}) = P_{friction}\ (v_{max}) + P_{air\ drag}\ (v_{max})$$

Overall applies, power is the product of the force and the speed or in symbols:

$$P = F * v$$

Power losses due to air drag:

$$F_{air\ drag} = \rho_{air} * A * C_w * \frac{v^2}{2}$$

With:

$\rho_{air} = 1{,}293\ kg/m^3$

$A = 0{,}02\ m^2$

$C_w = 0{,}5$

$v = v_{max}$

$$P_{air\ drag} = F_{air\ drag} * v$$

So: $$P_{air\ drag} = \rho_{air} * A * C_w * \frac{v_{max}^3}{2}$$

Power losses due to friction:

If we assume that the maximum speed will occur on the slope:

$$F_{friction} = C_{rr} * N * \cos\alpha$$

With:

$C_{rr} = 0{,}012$

$N = m * g = 1 * 9{,}81 = 9{,}81\ N$

$\cos\alpha = 7{,}18°$

$$P_{friction} = F_{friction} * v$$

So: $$P_{friction} = C_{rr} * N * \cos\alpha * v_{max}$$

To calculate v_{max}, we insert these previous expressions in:

$$P\ (v_{max,out}) = P_{friction}\ (v_{max}) + P_{air\ drag}\ (v_{max})$$

So: $$F_{max} * v_{max} = \rho_{air} * A * C_w * \frac{v_{max}^3}{2} + C_{rr} * N * cos\ \alpha * v_{max}$$

We know that: $P_{output} + P_{friction} + P_{air\ drag} = 6{,}616$ Watt.

Or: $$P_{friction} + P_{air\ drag} = 6{,}616 - P_{output}$$

So: $$P_{output\ @\ vmax} = 6{,}616 - P_{output\ @\ vmax}$$

And $$P_{output\ @\ vmax} = 3{,}308 \text{ Watt.}$$

If: $$P_{output\ @\ vmax} = F_{@\ vmax} * v_{max}$$

With:

$$F_{@\ vmax} = F_{friction} + F_{air\ drag} = C_{rr} * N * cos\ \alpha + \rho_{air} * A * C_w * \frac{v^2}{2}$$

So: $$0 = 6{,}456 * 10^{-3} * v^3 + 0{,}1168 * v - 3{,}308$$

We let Maple solve this equation:

$a := 0 = 6.456 \cdot 10^{-3} \cdot v^3 + 0.1168 \cdot v - 3.308$

$0 = 0.006456000000\ v^3 + 0.1168\ v - 3.308$

$solve(a, v)$

$7.250845522, -3.625422761 + 7.584376589\ I, -3.625422761 - 7.584376589\ I$

We find that: $v_{max} = 7{,}25\ m/s$.

$$P_{loss,air\ drag} = 2{,}464 \text{ Watt or } 7{,}76\%$$

$$P_{loss,friction} = 0{,}847 \text{ Watt or } 2{,}67\%$$

$$P_{output} = 3{,}305 \text{ Watt or } 10{,}41\%$$

Sankey diagram

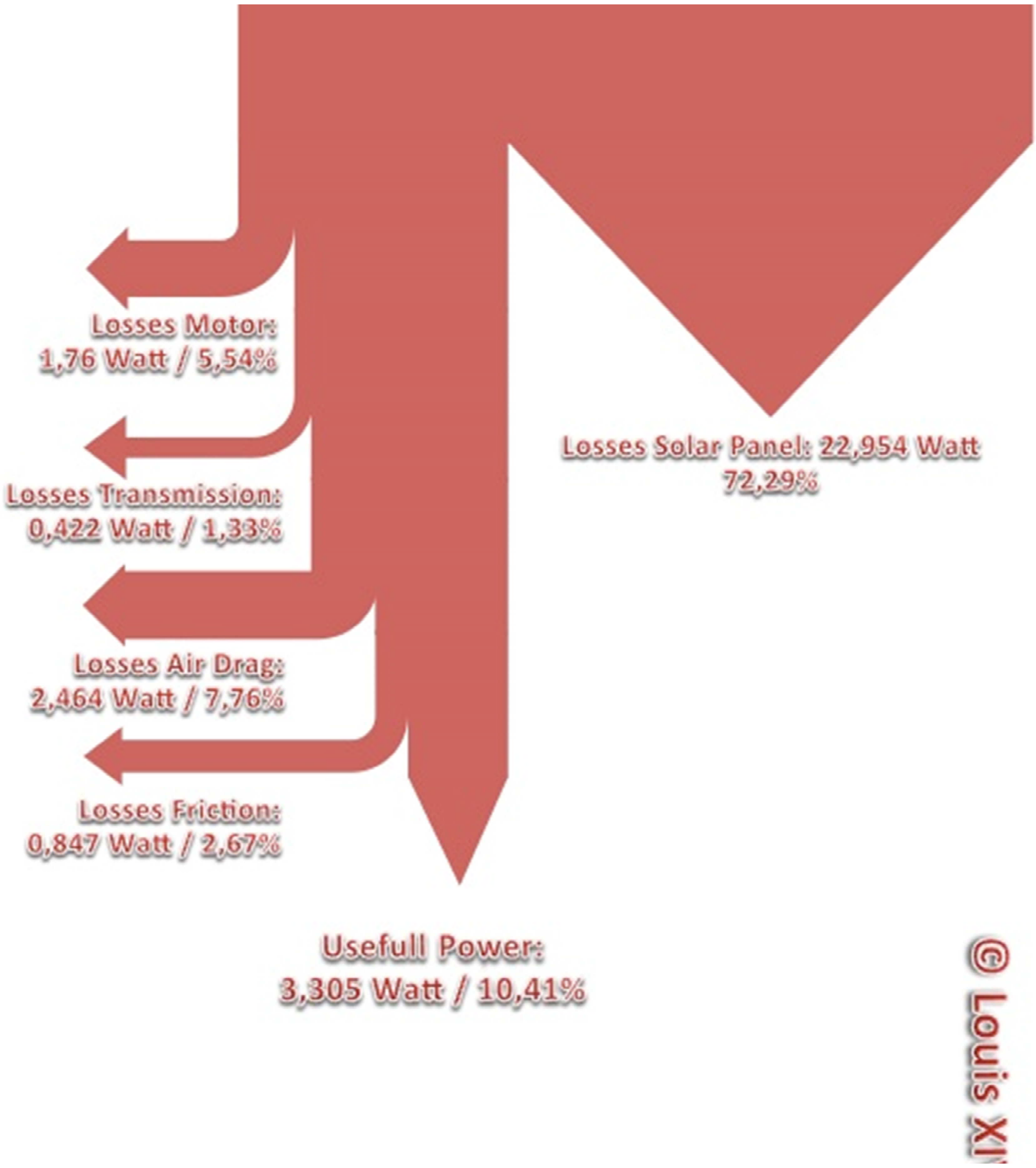


Figure 16: Sankey diagram at top speed

1.2 Case Simulink

1.2.1 Introduction

In this part of the case we have to simulate how the SSV will do on the real racetrack. To get to this part, we first need to simulate little parts to get used to the program. Simulink is an awesome program, which allows us to simulate the race without building the car in real. This will save us a lot of money. Because of this program we can adjust all the parameters to look for the best model.

First we have to calculate the best resistance, which would work with our solar panel. This is just an exercise to get used to Simulink and Matlab. After filling in all the parameters we can take a look at all the graphs. From here on we can take conclusions. Second of all we will calculate the distance that the vehicle will drive without any input of the solar panel. After this we have to simulate the whole race and look for improvements that we can apply to our vehicle. The last thing we have to do is to think about why this program is so good to use.

1.2.2 Questions

Question 1: Determine the resistor load value (10 to 100 Ohm) that makes the solar panel deliver maximum power.

To determine the resistor load value the following scheme (figure 12) was used. We've opened the documents that were on Toledo.

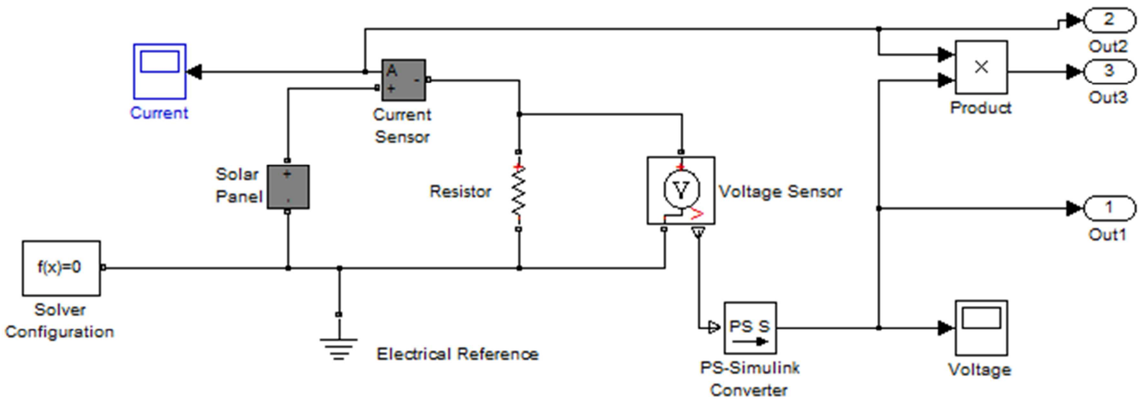


Figure 17: the scheme of the solar panel to determine the best load

After looking at the scheme, we opened Matlab to fill in all the parameters (figure 16).

```
>> clear all;
close all;

%%% Solar Power
Ir =  800    ;   % solar irradiance [W/m^2]
Is = 1e-8 ;   % saturation current [A]
Isc =  0.57   ;   % short circuit current [A]
Voc = 8.80/15    ;   % Open circuit voltage [V]
Ir0 = 700 ;   % irradiance used for measurements [W/m^2]
m =  1.23     ;   % diode quality factor

V=[];
I=[];
P=[];

% replace these values for the resistance with relevant values
R_list=[1 5 9 10 12 14 17 20 30 40 60 80 100];

for i=1:length(R_list)
    R=R_list(i)

    sim('Solar_panel_model',10); % Simulate Simulink model "Solar_panel_model.mdl" for 10 sec.

    V = [V yout(end,1)];
    I = [I yout(end,2)];
    P = [P yout(end,3)];
end

figure(1)
plot(V,I,'b*');
ylabel('Curent [A]');
xlabel('Voltage [V]');
axis([0 10 0 1.5]);
set(gcf,'color',[1 1 1])

figure(2)
plot(V,P,'r*');
ylabel('Power [W]');
xlabel('Voltage [V]');
axis([0 10 0 10]);
set(gcf,'color',[1 1 1])
```

Figure 18: Matlab parameters

After pressing the enter key, it started to calculate the current, voltage and power for all the different resistances. At the end it opened some graphs that gave us all the different points. We've got the voltage in function of the current graph and the voltage in function of the power graph. These are displayed below (figure 19 and figure 20).

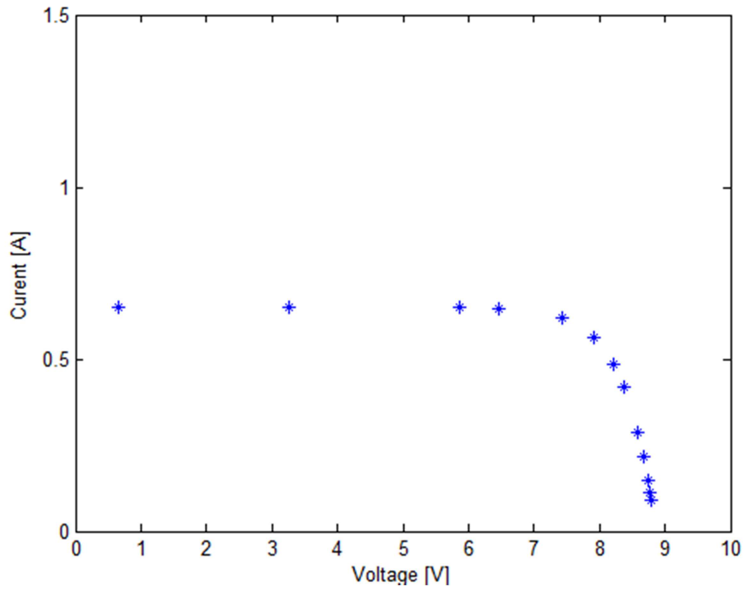


Figure 19: Voltage in function of Current

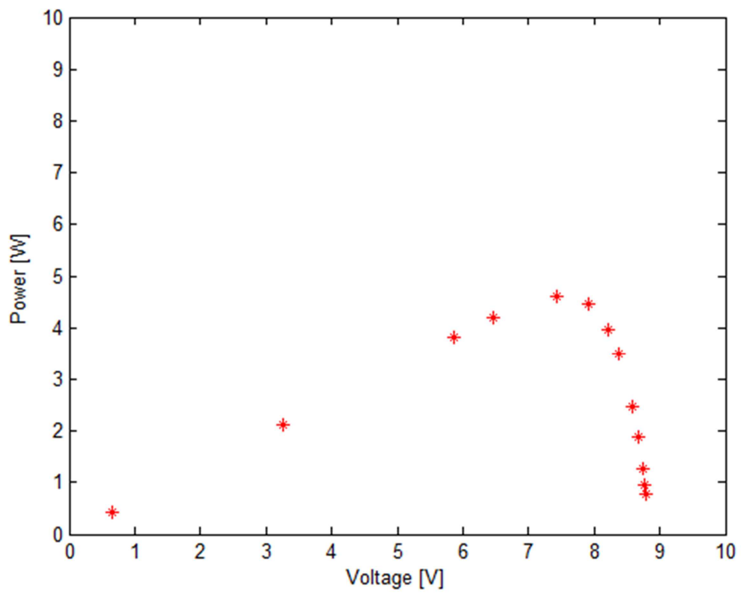


Figure 20: Voltage in function of Power

As you can see we get the maximum power at the 5th red star on figure 20. This means that the power is maximum at a resistance of 12 Ω. Resistances of less than 10 Ω were also used because otherwise the maximum wouldn't be clear to see.

Question 2: Determine the travel distance when the SSV drives down the slope.

To simulate the vehicle we started by thinking about all the frictions the car would undergo. These frictions are thanks to the air and the wheels, which will cause an air friction and a rolling friction. These will slow the vehicle down. There's also the gravity which will cause an acceleration when the vehicle goes down the slope.

For the first few meters the car goes down the slope. This will cause an acceleration because of the gravity. Just a small part of the gravity will cause a positive acceleration. This is the orange part on the scheme in figuur 22. All the forces will be added up and if it is divided by the mass of the vehicle it will give the acceleration.

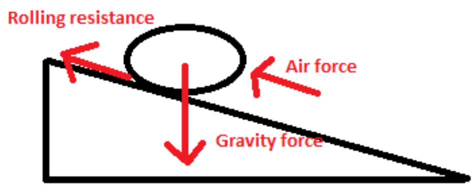


Figure 21: Forces on the vehicle

The green part has all the frictions except for the gravity, because there's a horizontal part after the slope. The gravity won't cause any positive or negative acceleration anymore. This is because the gravity is perpendicular on the ground.

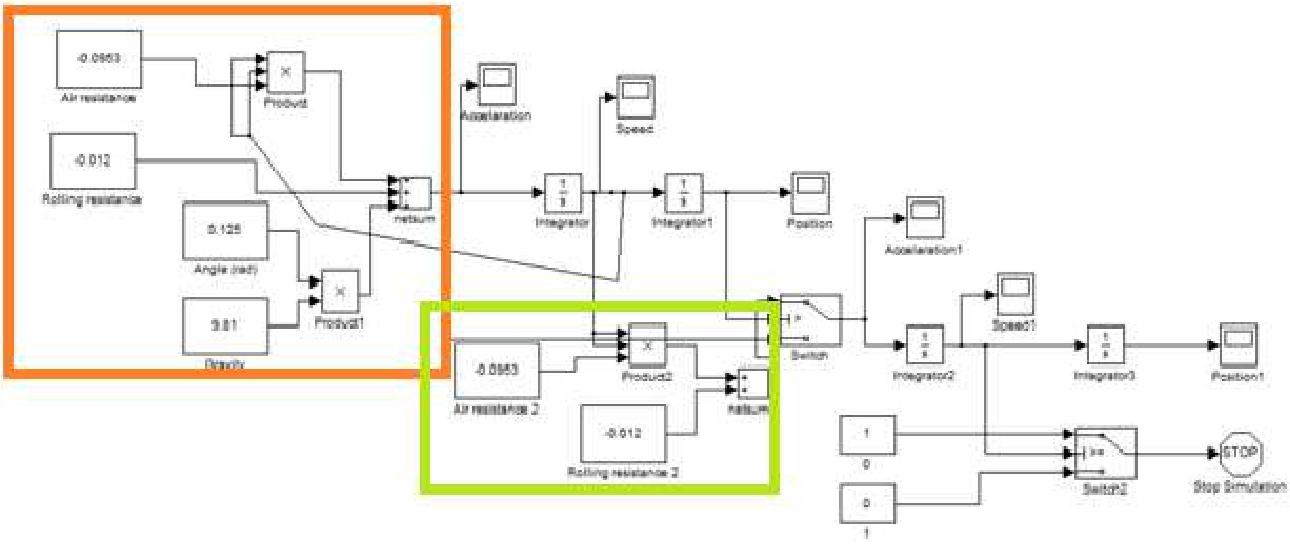


Figure 22: the scheme to determine the travel distance

When the acceleration is integrated we get the speed of the vehicle. Integrate it once more and the distance will be given. Behind the green and orange part there's a switch. Once the vehicle is off the slope, the gravity needs to be deleted. The switch switches from the orange part to the green one after it has travelled for 2 meters. Then again the acceleration will be given without the gravity. Integrating it will give us the speed and integrating it again will give us the position. The last switch will make the simulation stop when the speed of the vehicle is equal to zero.

After the simulation was ran the following graphs were given: the acceleration graph, the speed graph and the position graph.

After a few seconds the acceleration (figure 23) becomes negative. This means that the vehicle has begun its horizontal part. It keeps getting lower until the vehicle eventually stands still.

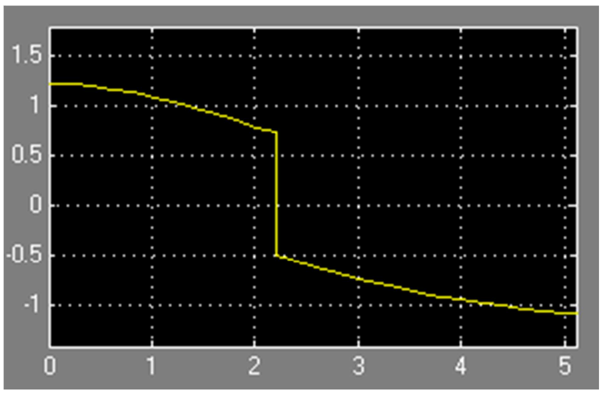


Figure 23: Acceleration during the track

In the speed graph (figure 24) we see the sudden change at 2.2 seconds. This means that the speed is lowering. After 4.9 seconds the speed is zero, this means that the vehicle is standing still.

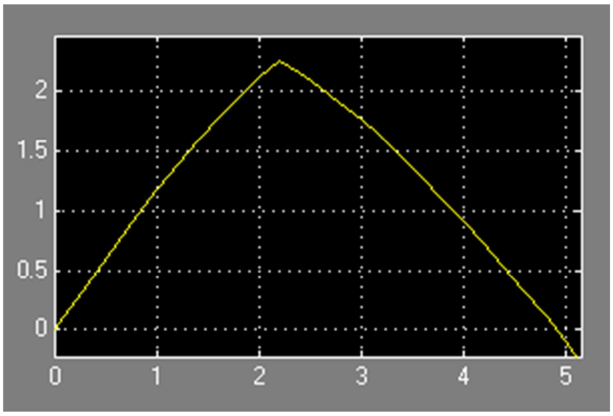


Figure 24: Speed during the track

The travel distance is accomplished after 4.9 seconds. The vehicle would travel a distance of 6 meters after rolling down a slope of 0.25 meters high for 2 meters.

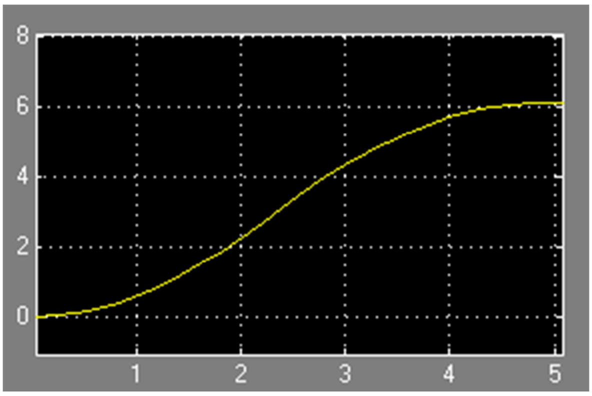


Figure 25: Distance during the track

Question 3: Simulate the race

To simulate the race all the different objects of the vehicle had to be added to Simulink. Thanks to the example on Toledo it has been able to build the simulation. As you are able to see in figure 26 all the different objects are made in Simulink.

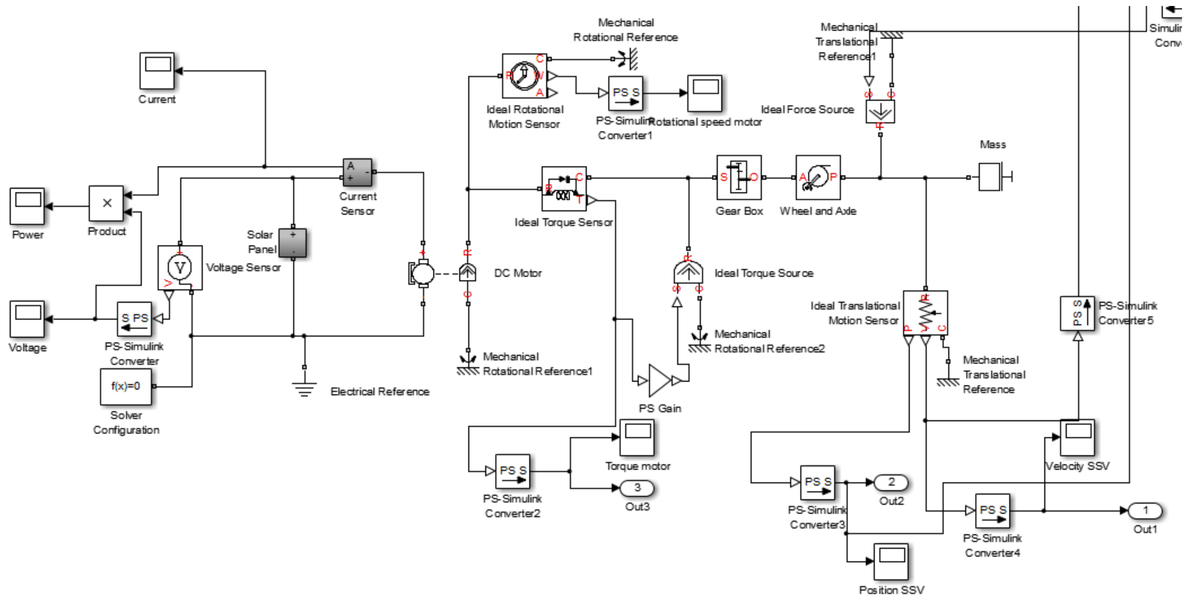


Figure 26: Scheme to simulate the race (part 1)

There still had to be made a second part that would take all the frictions into account. Because these objects weren't implemented in Simulink, it had to be made with our common sense. Almost the whole part from question 2 was useful now. Part 1 combined with question 2 would give the complete scheme to simulate the real race. Figure 27 is the part that completes the total scheme.

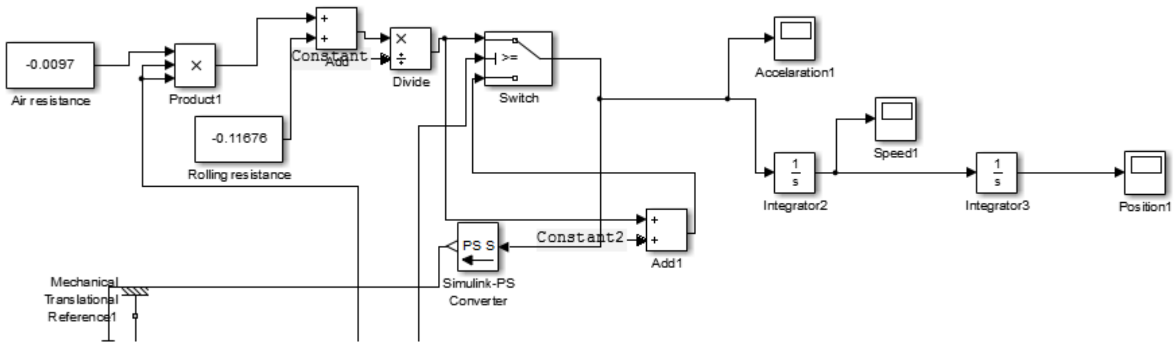


Figure 27: Scheme to simulate the race (part 2)

After filling in all the parameters (figure 28) of the solar panel, the DC motor, the mass, the gain, the gear box and the wheel and axle it was able to calculate the acceleration, speed and distance of the solar vehicle.

```
%%% Solar Power
Ir = 800;    % solar irradiance [W/m^2]
Is = 1e-8;    % saturation current [A]
Isc = 0.57;  % short circuit current [A]
Voc =25.7e-3 ;  % Open circuit voltage [V]
Ir0 = 800;  % irradiance used for measurements [W/m^2]
m = 1.23;     % diode quality factor

%%% Motor parameters
Ra = 3.32;     % ohm
Km = 8.55e-3;     % Nm/A
L  = 0.22e-3;     % H
Im =4.10 ;     % g*cm^2
Cm =8.9285e-4;

efficiency = 0.84;

%%% SSV parameter
mass = 0.886;  % kg
Cw   = 0.5;
A    = 0.03;   % m^2
rho = 1.293;   % kg/m^3
Crr = 0.012;

%%% Wheel radius
r =0.06;
```

Figure 28: Matlab parameters

When we take a look at the acceleration graph (figure 29), we see that it diminishes at four seconds. This means that the solar vehicle is finally at the slope. It starts with acceleration around the 1.1 m/s². When getting to the slope it only has an acceleration of 0.8 m/s². Finally getting up the slope it has an acceleration of -0.4 m/s². This means that the speed of the vehicle will diminish.

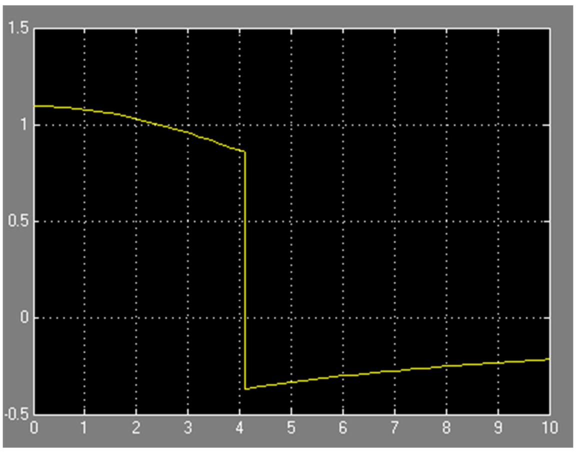


Figure 29: Acceleration during the race

At the start the speed of the vehicle increases (figure 30). At four seconds the vehicle gets to the slope. The maximum speed we accomplish to get should be around 4.25 m/s². Once the vehicle is on the slope, the speed will diminish and the vehicle will start to move slower.

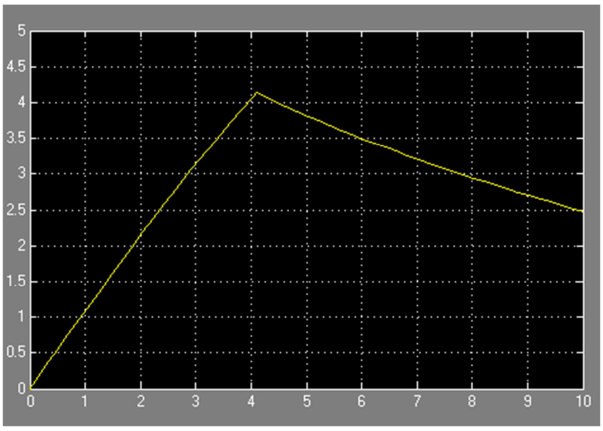


Figure 30: Velocity during the race

In the distance graph (figure 31) we see that we'll arrive the slope at around four seconds. The distance we travel afterwards will take longer because the slope will make it more difficult for the vehicle to finish the race. After the ten meters we still need to travel four meters (the slope). The total track will take around 5.5 seconds.

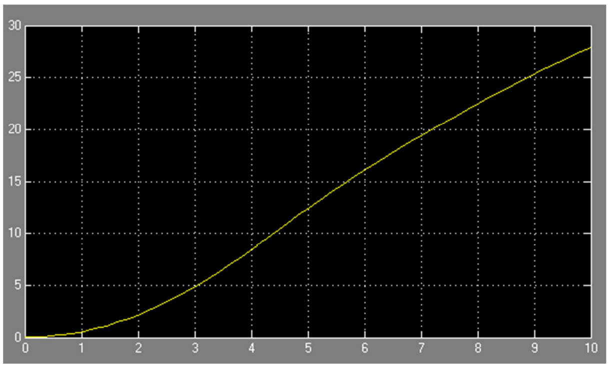


Figure 31: Distance during the race

Question 4: Why would you use such simulations?

Simulations are very important towards engineers, they give a realistic image of how something like a machine or a solar car will behave under certain circumstances. With this information, an engineer is able to improve his design without the need of actually building a prototype. This way of working is more indirect towards the desired product because there is no physical contact, but it allows doing several accurate tests on a short amount of time. Also, there is no need to make prototypes, which saves material cost and does not affect the environment. Therefore is making simulations an economical and an ecological way of designing your product.

1.3 Case SSV Part 2

1.3.1 Simulation for a better Sankey diagram

With the track available, we did some measurements to calculate the power losses in the transmission by letting our SSV roll down a slope of four meters two times. The first time with the gears inside, and the second time without the gears inside. By dividing the distances that the car had travelled in the two cases, it is possible to find the friction losses in the transmission. With this and other information like, the exact mass of the car and the new speeds calculated in a correct simulation, we are able to set up new diagrams for the two cases. Again we assume that the sun's radiation is 800 W/ m^2.

Total power available:

The solar panel contains 16 solar cells, which have a total surface of

$16 * (0{,}078\,m * 0{,}039\,m) = 0{,}048672\,m^2$. The total power delivered by the sun on our solar panel is then

$800\,W/m^2 * \; 0{,}048672\,m^2 = \; 38{,}938\,Watt$ and is the maximum power that the car can use during the race.

(We start with 38,938 Watt)

Power losses in the solar panel:

It is possible to calculate the power losses of the panel because in the lab, we tested the solar panel to calculate its diode factor with a lamp of 300 Watt/m^2. This was another sort of solar panel with 15 solar cells instead of 16. We will calculate the efficiency of the previous panel and use it as a guideline for our current solar panel.

The incoming power was $15 * (0{,}063 * 0{,}042)\,m^2 * 300\,Watt/m^2 = 11{,}907\,Watt$. The maximum measured power was 3,3 Watt. The efficiency can be calculated with these two values: 27,71%.

The total power loss due to the solar panel is: $(1 - 0{,}2771) * 38{,}938 \; = \; 28{,}148\,Watt$.

(We have 38,938 - 28,148 = 10,79 Watt left)

Power losses in the motor:

In the data sheet it is stated that the maximum efficiency is 84%. This occurs when there is no load connected to the motor and the motor reaches his maximum rpm. The real efficiency will be lower, we assume it will be around 80%.

So only 80% of the power delivered by the solar panel is transformed in power for the acceleration:

$$0{,}8 * 10{,}79 = 8{,}632 \text{ Watt. We lose } 2{,}158 \text{ Watt.}$$

(We keep 10,79 - 2,158 = 8,632 Watt left)

Power losses in the transmission:

When the SSV is built, we are able to test and calculate the efficiency and power losses in the transmission and the losses due to friction between axes and chassis. We do this by letting our SSV roll down a slope once with the gearbox installed and once without the gearbox installed. By calculating the ratio of the travelled distances we get the efficiency of our transmission. Without the transmission, the SSV travels around 9,4 meters while with the gearbox the SSV only covers 7,5 meters. Thus, the efficiency is 79,79%. In total we lose $8{,}632 * 0{,}2021 = 1{,}745$ Watt.

(We keep 8,632 - 1,745 = 6,887 Watt left)

All these losses have the same value for each of the following two cases because the velocity is never a variable in the calculation for these losses.

1.3.1.1 Case 1: Sankey diagram at x =10 meters.

$v(x = 10) = 4{,}75$ m/s . We get this value out of the Simulink simulation.)

Overall applies, power is the product of the force and the speed or in symbols:

$$P = F * v$$

Power losses due to air drag:

$$F_{air\ drag} = \rho_{air} * A * C_w * \frac{v^2}{2}$$

With:

$\rho_{air} = 1{,}293\ kg/m^3$

$A = 0{,}02\ m^2$

$C_w = 0{,}5$

$v = 3{,}25\ m/s$

$$P_{air\ drag} = F_{air\ drag} * v$$

So: $P_{air\ drag} = 0{,}693$ Watt

Power losses due to friction:

$$F_{friction} = C_{rr} * N$$

With:

$C_{rr} = 0{,}012$

$N = m * g = 0{,}886 * 9{,}81 = 8{,}7\ N$

$$P_{friction} = F_{friction} * v$$

So: $P_{friction} = 0{,}495$ Watt

We have a total power loss $P = P_{air\ drag} + P_{friction} = 0{,}693 + 0{,}495 = 1{,}188$ Watt.

This is 17,2% of the power that was available.

The resting power is 5,699 Watt or 14,6% of the total power.

Sankey diagram

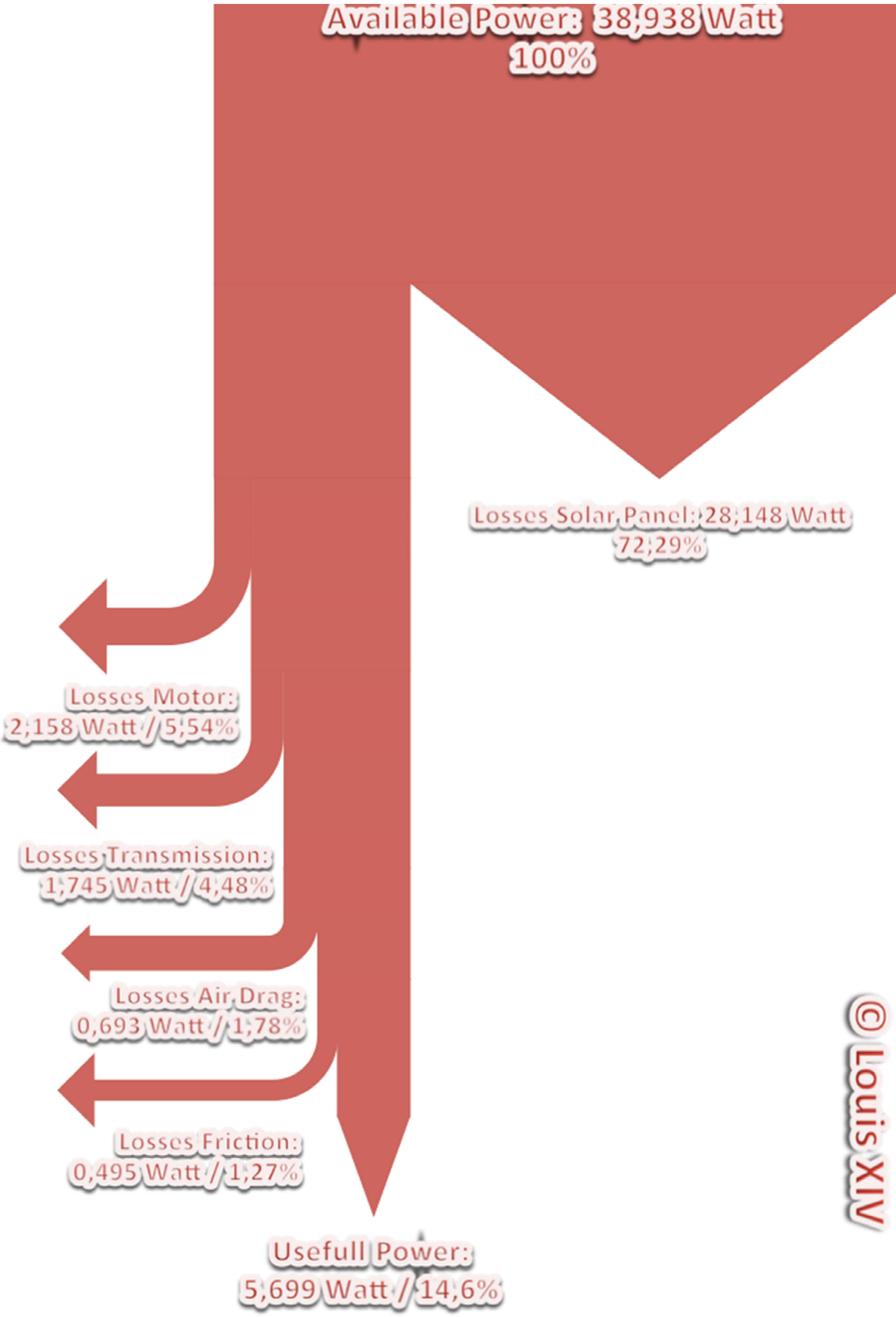


Figure 32: Sankey diagram at x=10

1.3.1.2 Case 2: Sankey diagram at the top speed.

We can calculate our theoretical maximum speed, at this point, there is no power left to accelerate. This means that our output power is equal to our friction and air drag power losses during the race.

$$P\ (v_{max,out})\ =\ P_{friction}\ (v_{max})\ +\ P_{air\ drag}\ (v_{max}) + P_{slope}\ (v_{max})$$

Overall applies, power is the product of the force and the speed or in symbols:

$$P = F * v$$

Power losses due to air drag:

$$F_{air\ drag} = \rho_{air} * A * C_w * \frac{v^2}{2}$$

With:

$\rho_{air}\ =\ 1{,}293\ kg/m^3$

$A = 0{,}02\ m^2$

$C_w = 0{,}5$

$v\ =\ v_{max}$

$$P_{air\ drag} = F_{air\ drag} * v$$

So: $P_{air\ drag}\ =\ \rho_{air} * A * C_w * \frac{v_{max}^3}{2}$

Power losses due to friction:

If we assume that the maximum speed will occur on the slope:

$$F_{friction} = C_{rr} * N$$

With:

$C_{rr} = 0{,}012$

$\alpha\ =\ 7{,}18°$

$N\ =\ m * g * sin(90° - \alpha) = 8{,}624\ N$

$$P_{friction} = F_{friction} * v$$

So: $P_{friction}\ =\ C_{rr} * N *\ v_{max}$

Power losses due to the slope:

Due to the slope, the SSV will also lose some power.

$$F_{slope} = N * cos(90° - \alpha)$$

With:

$\alpha = 7{,}18°$

$N = m * g * sin(90° - \alpha)$

So: $P_{slope} = N * cos(90° - \alpha) * v_{max}$

To calculate v_{max}, we insert these previous expressions in:

$P\ (v_{max,out}) = P_{friction}\ (v_{max}) + P_{air\ drag}\ (v_{max}) + P_{slope}(v_{max})$

$$F_{max} * v_{max} = \rho_{air} * A * C_w * \frac{v_{max}^3}{2} + C_{rr} * N * v_{max} + N * cos(90° - \alpha) * v_{max}$$

We know that: $P_{output} + P_{friction} + P_{air\ drag} + P_{slope} = 6{,}887$ Watt

Or: $P_{friction} + P_{air\ drag} + P_{slope} = 6{,}887 - P_{output}$

So: $P_{output\ @\ vmax} = 6{,}887 - P_{output\ @\ vmax}$

And $P_{output\ @\ vmax} = 3{,}444$ Watt.

If: $P_{output\ @\ vmax} = F_{@\ vmax} * v_{max}$

With:

$$F_{@\ vmax} = F_{friction} + F_{air\ drag} + P_{slope}$$

$$= C_{rr} * N + \rho_{air} * A * C_w * \frac{v^2}{2} + N * cos(90° - \alpha)$$

So: $0 = 6{,}465 * 10^{-3} * v^3 + (0{,}103488 + 1{,}077887) * v - 3{,}444$

We let Maple solve this equation:

```
a := 6.465·10^-3·v^3 + (0.103488 + 1.077887)·v = 3.44
                                        0.006465000000 v^3 + 1.181375 v = 3.44
solve(a, v)
                    2.792671095, -1.396335548 + 13.73256025 I, -1.396335548 - 13.73256025 I
```

We find that: $v_{max} = 2{,}793\ m/s$.

This speed is lower than the speed when the SSV had travelled a distance of 10 meters because we assume that the car starts at the beginning of the slope. When our car reaches the slope with already a certain velocity it will slow down to this speed.

$$P_{loss,air\ drag} = 0{,}141 \text{ Watt or } 0{,}36\% \text{ of the total available power.}$$

$P_{loss,friction}$ = 0,289 Watt or 0,74% of the total available power.

$P_{loss,slope}$ = 3,011 Watt or 7,73% of the total available power.

P_{output} = 3,444 Watt or 8,83% of the total available power.

Sankey diagram

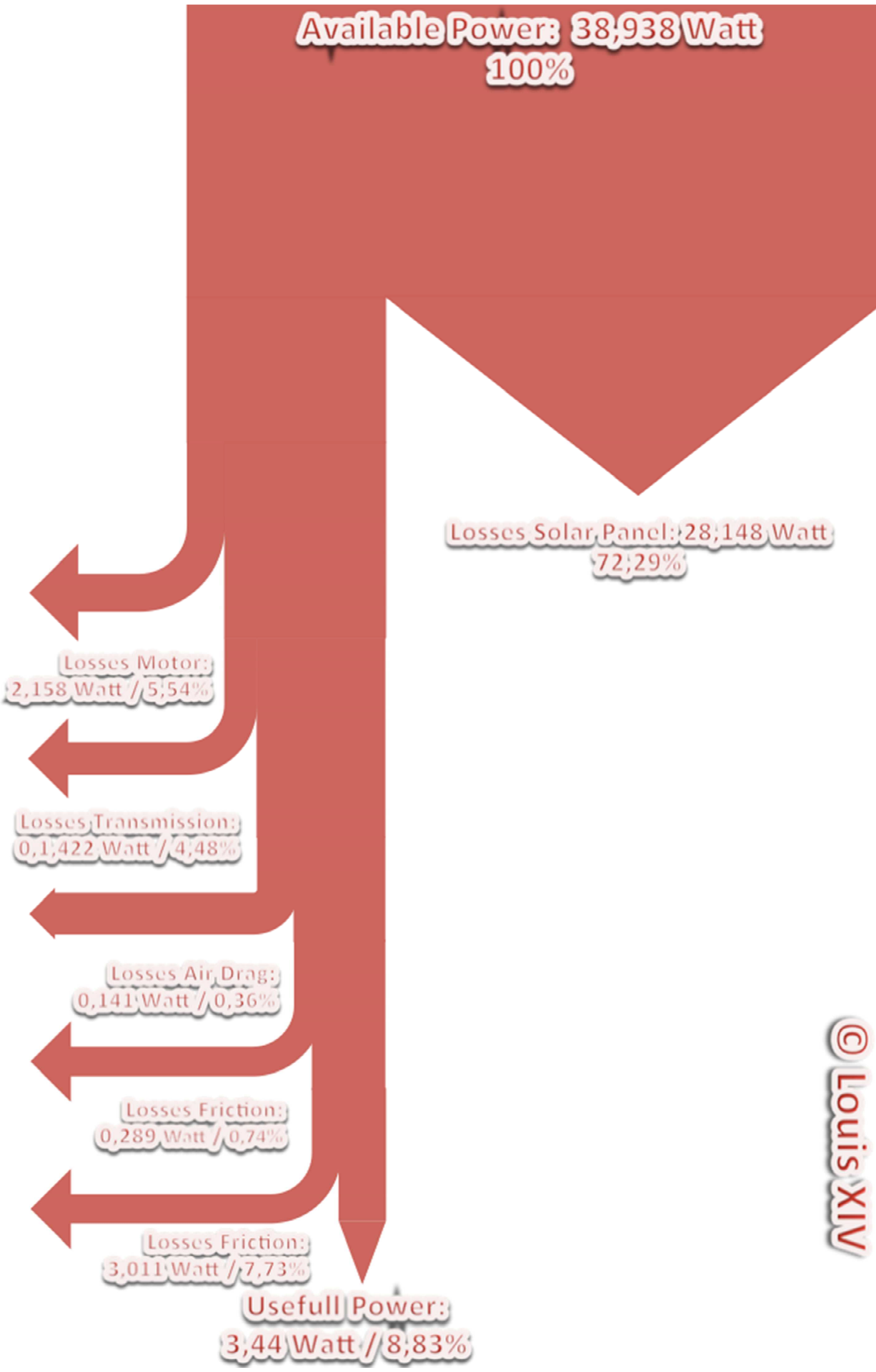


Figure 33: Sanky diagram at top speed

1.3.2 Critical loaded components analysis

1.3.2.1 Introduction

In this part of Case part 2 we had to make an analysis of the dimensions of the critically loaded components. First in this part we will give some more explanation about the drive shaft and all the forces on this drive shaft. There were two situations given: *The SSV shall accelerate from a standstill and the will deliver a maximum torque and keep in mind that the wheels do not slip; the speed will be maximal and the torque is smaller.* Afterwards the situations will be studied and a bending moment and a torsion diagram will be showed. Every situation contains also a Von Mises calculation.

1.3.2.2 Description of the shaft

The drive shaft is indicated in figure 34 in the color green. The figure shows also the forces on the driving shaft, see the red arrows.

The drive shaft has a length of 0,175 m. On the drive shaft are the two back wheels with a diameter of 11 centimeters, a driving gear with a diameter of 10 centimeters and two bearings attached. The driving gear together with two other smaller gears with a ratio of 1:10 will provide the transmission of the SSV. The last gear with a diameter of 1 centimeter is placed directly onto the motor. The bearings are encapsulated in two Plexiglas bearing holders. These two bearing holders are placed between the two frame plates.

1.3.2.3 Normal forces on the axel due to the weight of the SSV

The total mass of the car is 886.02 grams. To determine the forces on the wheels, we put the car on a weighing scale. We used one scale to measure the forces on the rear wheels and used another to measure the forces on the front wheels. A scale measures the force which is generated by the wheels and divides it by the gravitational acceleration, therefore showing a mass on its display. We recalculate these forces by multiplying the mass with the gravitational acceleration. The mass on the front wheels was 301.7g and the mass on the rear wheels was 584.1g. The total weight of the car in our measurement therefore is 885.8g, which is a decent approximation of the real weight.

Because our SSV consists of two rear wheels the 584.1grams are divided among the two them. Each wheel carries a mass of 292.05g. Or in other words a force of 2,865N.

$F_{\text{rear wheel}} = m*g = 292.05*(10\text{^}-3)kg * 9.81N/kg = 2,865N$

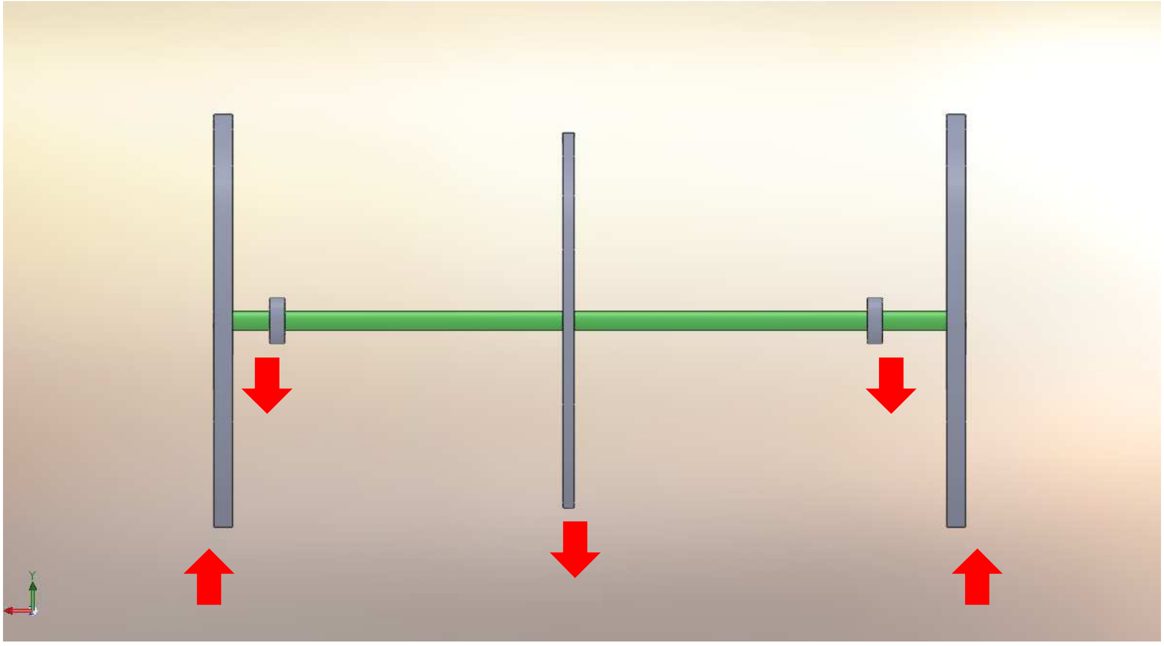


Figure 34: Driving shaft with rear wheels

1.3.2.4 Forces on axel due to driving gear

The driving gear itself has a mass of 21g. This mass will have an impact on the shaft due to gravity. The force that is transmitted on the total length of the shaft due to gravity is 41,2 N/m.

$F_{gear1} = m*g = 21*10^{-3}\ kg * 9.81N/kg = 0,206\ N$

$Q_{gear1} = \frac{F(gear)}{l(gear)} = \frac{0,206\ N}{0,005\ m} = 41,2\ N/m$

The rotation of the motor is transferred onto the shaft using three gears with a ratio of 1/10. The largest gear, directly assembled on the driving shaft, creates a momentum on the shaft. During takeoff, the motor generates a certain torque. To calculate this torque we multiply the torque constant with the maximum current that our solar panel can deliver.

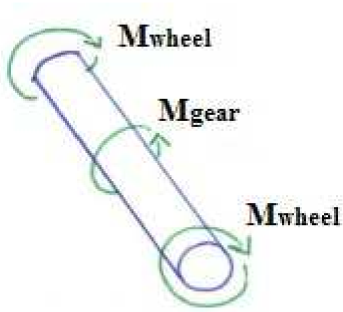


Figure 35: Moments of the driving shaft

$M_{gear} = 8,55mNm/A * 0,88\ A = 7,524*10^{-3}\ Nm$

This torque is delivered by the second gear onto the last gear with a gear ratio of 1/10. This means the last gear will have a torque of ten times the calculated torque of the motor.

$M_{gear} = 10 * 7,524*10^{-3}\ Nm = 75,24*10^{-3}\ Nm$

The momentum of the gear is a result of the force transferred from second gear. This momentum generates a force on the shaft (See figure 36). This force is equal to 0,684 N and has a component in two directions. The angle of the forces is derived from the pressure angle of

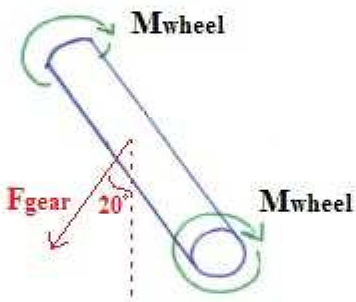


Figure 36: Moments and force of the gear

the gears which is, in our case, equal to 20degrees. The divided force on the shaft is 136,8 N/m.

$$M_{gear} = F_{gear} * x$$

$$F_{gear2} = \frac{Mgear}{x}$$

$$F_{gear2} = \frac{75,24*10^{-3}\ Nm}{0,094\ m} = 0,800\ N$$

$$Q_{gear2} = \frac{0,800\ N}{0,005\ m} = 160,1\ N/m$$

1.3.2.5 Forces on shaft due to bearings

The weight of the bearings will generate a force on the shaft due to gravity. Each bearing weighs 2 grams. We obtain a force of 0,0196 N. The distributed Force is therefore equal to 4,91 N/m.

$$F_{bearing} = m*g = 2*10^{-3}\ kg * 9,81\ N/kg = 0,0196\ N$$

$$Q_{bearing} = \frac{F(bearing)}{l(bearing)} = \frac{0,0196\ N}{0,004\ m} = 4,91\ N/m$$

The force of each bearing working on the shaft is equal to 0,0196 N, therefore:

$$Q_{bearing} = \frac{F(bearing)}{l(bearing)} = \frac{0,0196\ N}{0,011\ m} = 1,782\ N/m$$

Forces on shaft due to weight of the body

The weight of the SSV rests upon the bearings. We will try to find this weight using Newton equilibrium in the Y-direction.

$$\Sigma y = 0 \rightarrow 2*F_{wheel} - 2*F_{Bearing} - F_{Gear1} - F_{Gear2,y} - F_{weight} = 0$$

$$\rightarrow F_{weight} = 2*F_{wheel} - 2*F_{Bearing} - F_{Gear1} - F_{Gear2,y}$$

$$\rightarrow F_{weight} = 2*(2,865N) - 2*(0,0196N) - (0,752\ N) - (0,206\ N)$$

$$\rightarrow F_{weight} = 4,733\ N$$

This means that 4,733 N works on the shaft due to the weight of the SSV. In other words, each bearing carries 2,366 N.

1.3.2.6 Acceleration from standstill with a maximum torque

The SSV accelerates from standstill and the motor delivers maximum torque. The wheels do not slip.

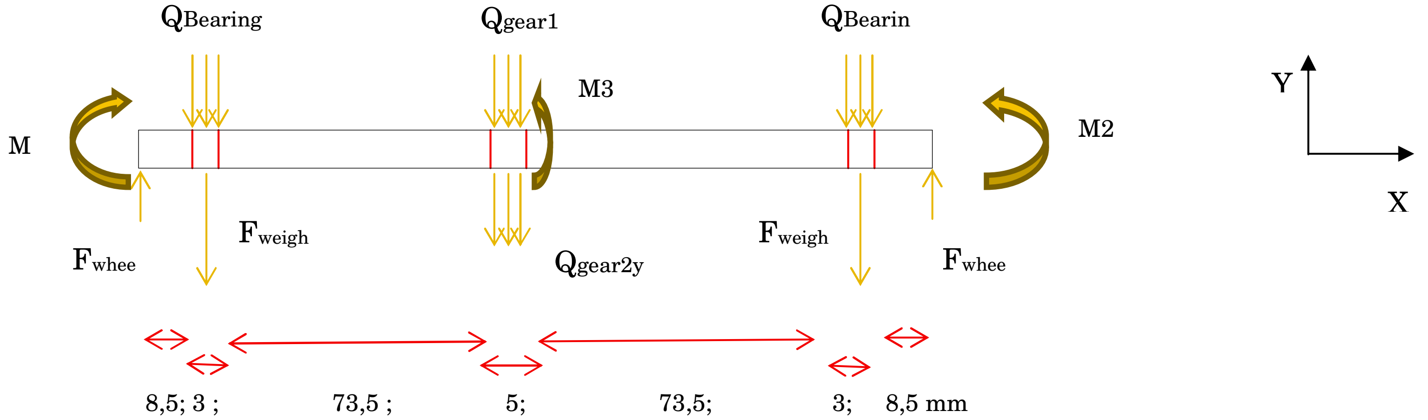


Figure 37: Driving shaft: maximum torque

For simplicity's sake we substitute the divided forces Q with their force centered in the middle of each area.

- M_3 = $75{,}24*10^{-3}$ Nm (Torque constant * $I_{max,solar\ panel}$) Found on datasheet Dc motor + solar panel
- M_1 = $M_2 = M_3/2 = 37{,}6*10^{-3}$ Nm
- F_{wheel} = 2,865N
- $F_{bearing}$ = 0,0196 N
- F_{weight} = 2,366 N
- F_{gear1} = 0,206 N
- $F_{gear2,y}$ = $F_{gear2} * \cos(20)$ = 0,752 N
- $F_{gear2,z}$ = $F_{gear2} * \sin(20)$ = 0,274 N

Simplification

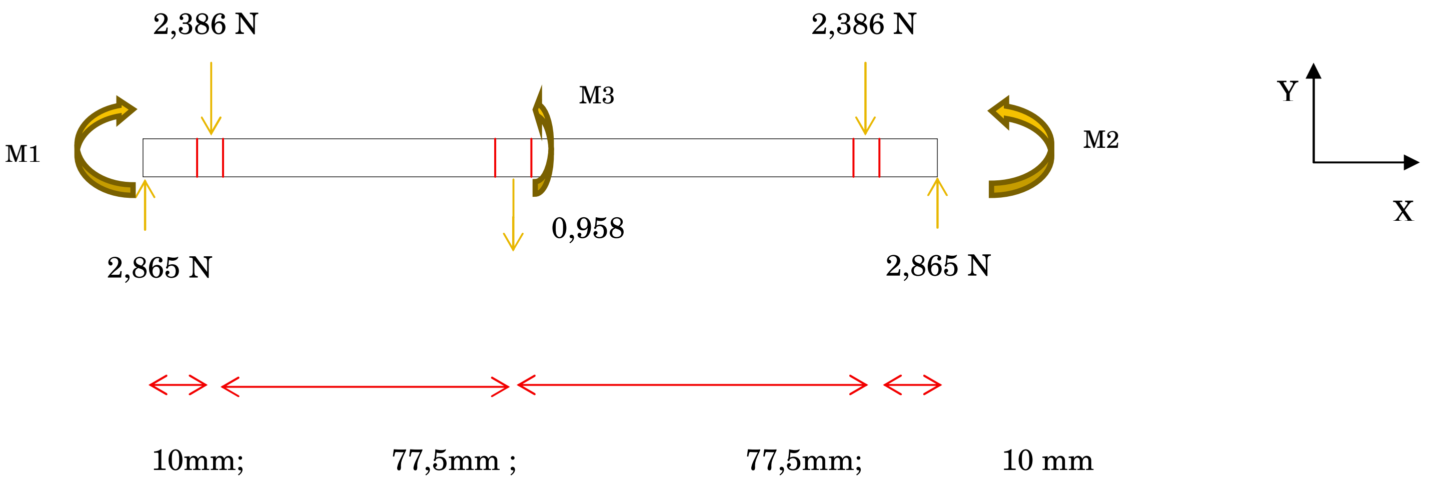


Figure 38: Driving shaft: maximum torque (simplification)

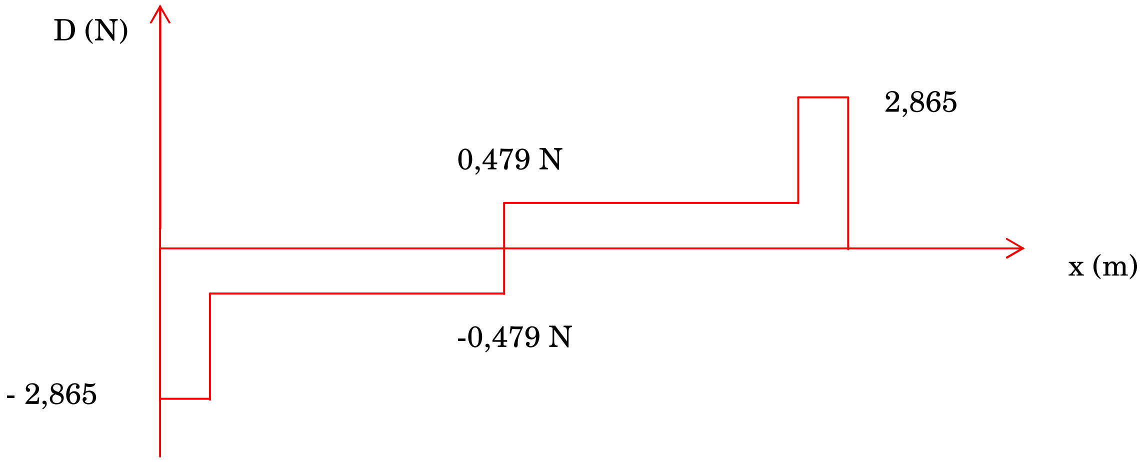


Figure 39: Shear force diagram

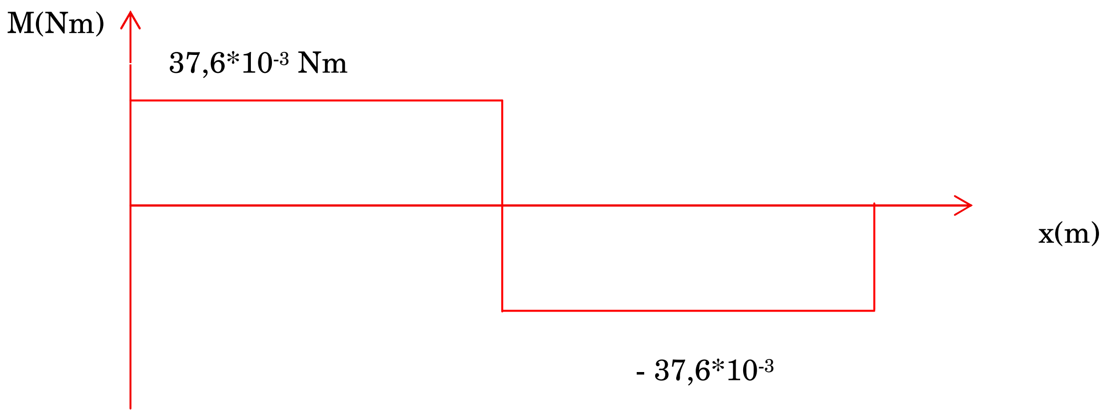


Figure 40: Moment diagram

Von Mises calculation:

We are going to calculate the equivalent tension using Von Mises.

$$\sigma_{vgl} = \frac{1}{\sqrt{2}}\sqrt{[(\sigma_{xx} - \sigma_{yy})^2 + (\sigma_{yy} - \sigma_{zz})^2 + (\sigma_{zz} - \sigma_{xx})^2 + 6\sigma_{xy}^2 + 6\sigma_{yz}^2 + 6\sigma_{zx}^2]}$$

a) We'll do the calculation on the point of the shaft were **the gear** is attached.

$\tau_X = 0$ Pa

$$\tau_Z = \frac{Fgear2,z}{r^2 * pi} = \frac{Fgear2 * \sin(20)}{r^2 * pi} = \frac{0{,}274\ N}{(0{,}0025m)^2 * 3{,}14} = 13{,}96\ KPa$$

$$\tau_Y = \frac{Fgear2,Y}{r^2 * pi} = \frac{Fgear2 * \cos(20)}{r^2 * pi} = \frac{0{,}752\ N}{(0{,}0025m)^2 * 3{,}14} = 38{,}32\ KPa$$

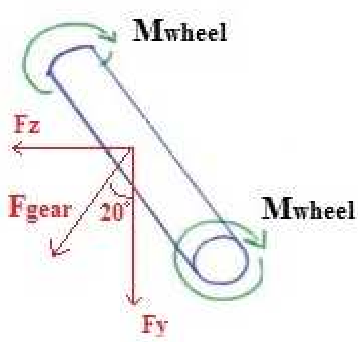


Figure 41: Drive shaft and force of gear

From this calculations we obtain the equivalent tension using Von Mises.

$\sigma_{VM} = \frac{1}{\sqrt{2}} \sqrt{6 * (\tau z)^2 + 6 * (\tau y)^2}$ = 70,6 KPa

b) Now we'll do the calculation on the point of the shaft were **the bearing** is attached.

τ_X = 0 Pa

τ_Z = 0 Pa

$\tau_Y = \frac{2{,}386\ N}{r^2 * pi} = \frac{2{,}386\ N}{(0{,}0025m)^2 * 3{,}14}$ = 121,6 KPa

From this calculations we obtain the equivalent tension using Von Mises.

$\sigma_{VM} = \frac{1}{\sqrt{2}} \sqrt{6 * (\tau y)^2}$ = 210,6 KPa

c) Now we'll do the calculation on the point of the shaft were **wheel** is attached.

τ_X = 0 Pa

τ_Z = 0 Pa

$\tau_Y = \frac{2{,}865\ N}{r^2 * pi} = \frac{2{,}865\ N}{(0{,}0025m)^2 * 3{,}14}$ = 146,0 KPa

From this calculations we obtain the equivalent tension using Von Mises.

$\sigma_{VM} = \frac{1}{\sqrt{2}} \sqrt{6 * (\tau y)^2}$ = 252,9 KPa

The Von Mises tension is maximum at the place where the wheels are attached.

1.3.2.7 Speed is maximal, torque is smaller

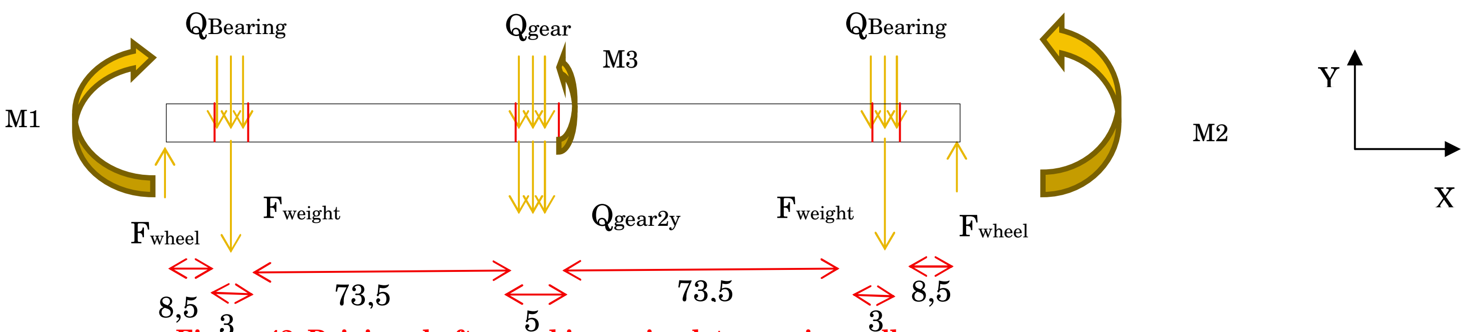


Figure 42: Driving shaft: speed is maximal, torque is smaller

To calculate the momentums on the wheels (M1, M2)

The maximum speed is 7,44 m/s (see Simulink exercise 3).

- $v = r * \omega \Rightarrow \omega = \frac{v}{r} = \frac{7{,}44\frac{m}{s}}{0{,}055m}$ = 135,3 rad/s

The power can be found in the Sankey diagram

- $P = T*\omega \Rightarrow T = \frac{P}{\omega} = \frac{3,44\ W}{135,3\ \frac{rad}{s}} = 0,0254$ Nm

- So $M_1 = M_2 = \frac{T}{2} = 0,013$ Nm

We clearly see that the Torque of the gear in this case is much smaller than in the first calculations, where the torque was 0,07524 Nm. Because in this case the torque is different, the force on the shaft (due to this torque) will be different as well. As explained before, this momentum generates a force on the shaft is in this case equal to 0,138 N and also has a component in two directions. The angle of the forces is 20degrees. The divided force on the shaft is 27,6 N/m.

$$F_{gear2} = \frac{\text{Mgear}}{x} = \frac{0,013\ \text{Nm}}{0,094\ m} = 0,138\ \text{N}$$

$$Q_{gear2} = \frac{0,138\ \text{N}}{0,005\ m} = 27,6\ \text{N/m}$$

- F_{wheel} = different than before
- $F_{bearing}$ = 0,0196 N
- F_{weight} = 2,366 N
- F_{gear1} = 0,206 N
- $F_{gear2,y}$ = F_{gear2} * cos(20) = 0,130 N
- $F_{gear2,z}$ = F_{gear2} * sin(20) = 0,047 N

Because the SSV is at top speed, the normal force on the wheels will be different. We calculate this force with Newton's equilibrium in the Y direction.

$$\Sigma y = 0 \rightarrow 2*F_{wheel} - 2*F_{Bearing} - F_{Gear1} - F_{Gear2,y} - 2*F_{weight} = 0$$
$$\rightarrow 2*F_{wheel} = 2*F_{Bearing} + F_{Gear1} + F_{Gear2,y} + 2*F_{weight}$$
$$\rightarrow 2*F_{wheel} = 2*(0,0196\text{N}) + (0,130\ \text{N}) + (0,206\ \text{N}) + 2*(2,366\ \text{N})$$
$$\rightarrow 2*F_{wheel} = 5,107\ \text{N}$$
$$\rightarrow F_{wheel} = 2,554\ \text{N}$$

Simplification

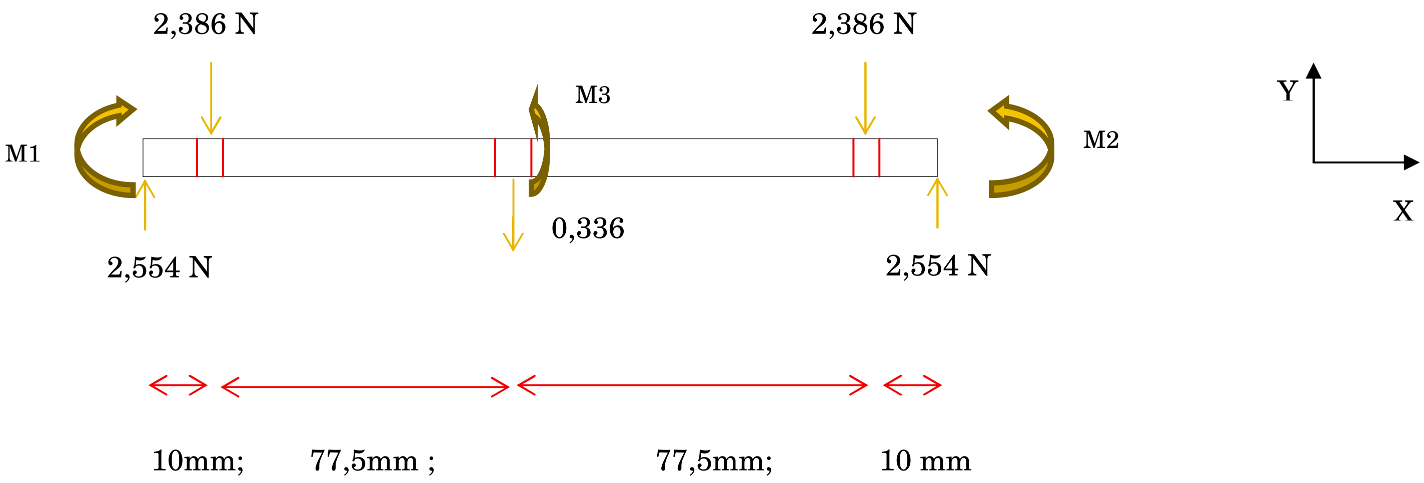


Figure 43: Driving shaft: speed is maximal, torque is smaller (simplification)

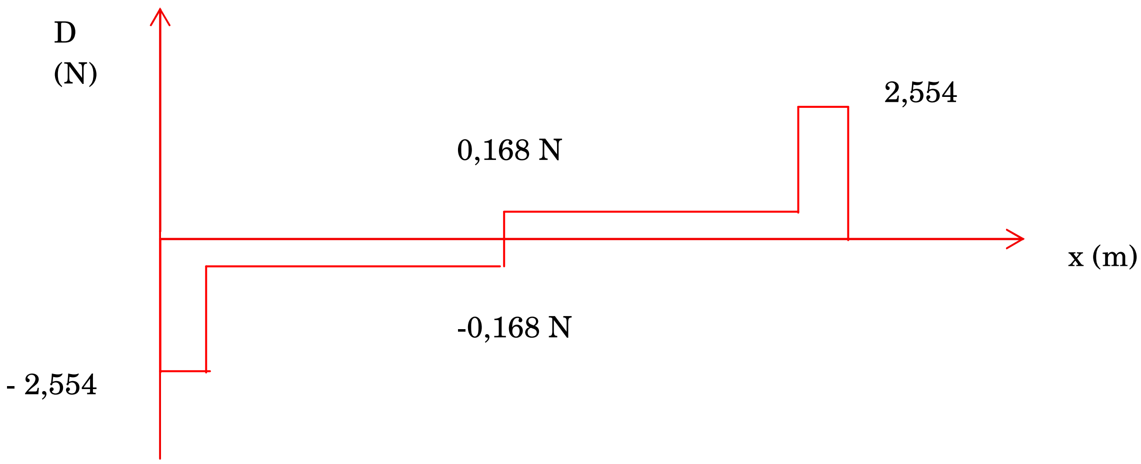


Figure 44: Shear force diagram

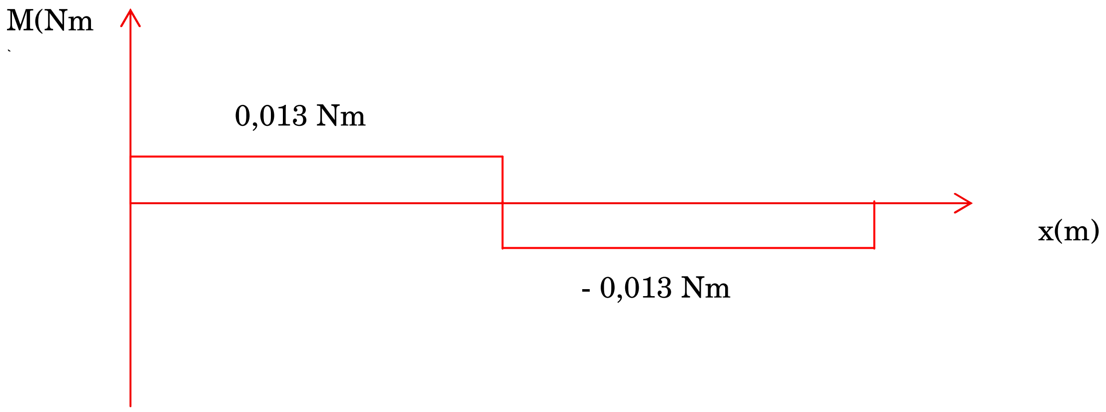


Figure 45: Moment diagram

- **Von Mises calculation:**

We are going to calculate the equivalent tension using Von Mises.

$$\sigma_{vgl} = \frac{1}{\sqrt{2}}\sqrt{[(\sigma_{xx}-\sigma_{yy})^2+(\sigma_{yy}-\sigma_{zz})^2+(\sigma_{zz}-\sigma_{xx})^2+6\sigma_{xy}^2+6\sigma_{yz}^2+6\sigma_{zx}^2]}$$

We'll do the calculation on the point of the shaft were the gear is attached.

$\tau_X = 0$ Pa

$$\tau_Z = \frac{F_{gear2,z}}{r^2 * pi} = \frac{F_{gear2} * \sin(20)}{r^2 * pi} = \frac{0{,}047\ N}{(0{,}0025m)^2 * 3{,}14} = 2{,}39\ KPa$$

$$\tau_Y = \frac{F_{gear2,Y}}{r^2 * pi} = \frac{F_{gear2} * \cos(20)}{r^2 * pi} = \frac{0{,}130\ N}{(0{,}0025m)^2 * 3{,}14} = 6{,}62\ KPa$$

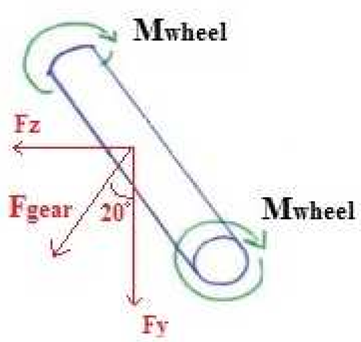


Figure 46: Drive shaft and force of gear

From this calculations we obtain the equivalent tension using Von Mises.

$$\sigma_{VM} = \frac{1}{\sqrt{2}}\sqrt{6 * (\tau z)^2 + 6 * (\tau y)^2} = 12{,}2\ KPa$$

b) Now we'll do the calculation on the point of the shaft were **the bearing** is attached.

$\tau_X = 0$ Pa

$\tau_Z = 0$ Pa

$$\tau_Y = \frac{2{,}386\ N}{r^2 * pi} = \frac{2{,}386\ N}{(0{,}0025m)^2 * 3{,}14} = 121{,}6\ KPa$$

From this calculations we obtain the equivalent tension using Von Mises.

$$\sigma_{VM} = \frac{1}{\sqrt{2}}\sqrt{6 * (\tau y)^2} = 210{,}6\ KPa$$

c) Now we'll do the calculation on the point of the shaft were **wheel** is attached.

$\tau_X = 0$ Pa

$\tau_Z = 0$ Pa

$$\tau_Y = \frac{2{,}554\ N}{r^2 * pi} = \frac{2{,}554\ N}{(0{,}0025m)^2 * 3{,}14} = 130{,}1\ KPa$$

From this calculations we obtain the equivalent tension using Von Mises.

$$\sigma_{VM} = \frac{1}{\sqrt{2}}\sqrt{6 * (\tau y)^2} = 226{,}4\ KPa$$

The Von Mises tension is maximum at the place where the wheels are attached.

- **Calculation of maximum speed and Power for situation 2**

We can calculate our theoretical maximum speed, at this point, there is no power left to accelerate. This means that our output power is equal to our friction and air drag power losses during the race. We suppose that this happens at a flat surface.

$$P\ (v_{max,out}) = P_{friction}\ (v_{max}) + P_{air\ drag}\ (v_{max})$$

Overall applies, power is the product of the force and the speed or in symbols:

$$P = F * v$$

Power losses due to air drag:

$$F_{air\ drag} = \rho_{air} * A * C_w * \frac{v^2}{2}$$

With:

$\rho_{air} = 1{,}293\ kg/m^3$

$A = 0{,}02\ m^2$

$C_w = 0{,}5$

$v = v_{max}$

$$P_{air\ drag} = F_{air\ drag} * v$$

So: $P_{air\ drag} = \rho_{air} * A * C_w * \frac{v_{max}^3}{2}$

Power losses due to friction:

If we assume that the maximum speed will occur on the slope:

$$F_{friction} = C_{rr} * N$$

With:

$C_{rr} = 0{,}012$

$\alpha = 7{,}18°$

$N = m * g = 8{,}962N$

$$P_{friction} = F_{friction} * v$$

So: $P_{friction} = C_{rr} * N * v_{max}$

To calculate v_{max}, we insert these previous expressions in:

$$P\ (v_{max,out}) = P_{friction}\ (v_{max}) + P_{air\ drag}\ (v_{max})$$

$$F_{max} * v_{max} = \rho_{air} * A * C_w * \frac{v_{max}^3}{2} + C_{rr} * N * v_{max}$$

We know that: $P_{output} + P_{friction} + P_{air\ drag}$ = 6,887 Watt

Or: $P_{friction} + P_{air\ drag} = 6{,}887 - P_{output}$

So: $P_{output\ @\ vmax} = 6{,}887 - P_{output\ @\ vmax}$

And $P_{output\ @\ vmax}$ = 3,444 Watt.

If: $P_{output\ @\ vmax} = F_{@\ vmax} * v_{max}$

With:

$$F_{@\ vmax} = F_{friction} + F_{air\ drag}$$

$$= C_{rr} * N + \rho_{air} * A * C_w * \frac{v^2}{2}$$

So: $0 = 6{,}465 * 10^{-3} * v^3 + 0{,}1043 * v - 3{,}444$

We let Maple solve this equation:

$$a := 0 = \frac{1.293 \cdot 0.5 \cdot 0.02}{2} \cdot v^3 + 0.012 \cdot 9.81 \cdot 0.886 \cdot v - 3.44$$

$$0 = 0.006465000000\ v^3 + 0.10429992\ v - 3.44$$

solve(a, v)

7.441292434, -3.720646217 + 7.593591799 I, -3.720646217 − 7.593591799 I

We find that: $v_{max} = 7{,}44\ m/s.$

P_{output} = 3,444 Watt

1.3.3 2D drawings of the frame of LOUIS XIV

To provide information about how our solar car is put together, a clear picture was made by an exploded view (figure 47). In the exploded view, it is clearly visible how each part is connected with the rest. Each component was individually dimensioned in Appendix annex 5.

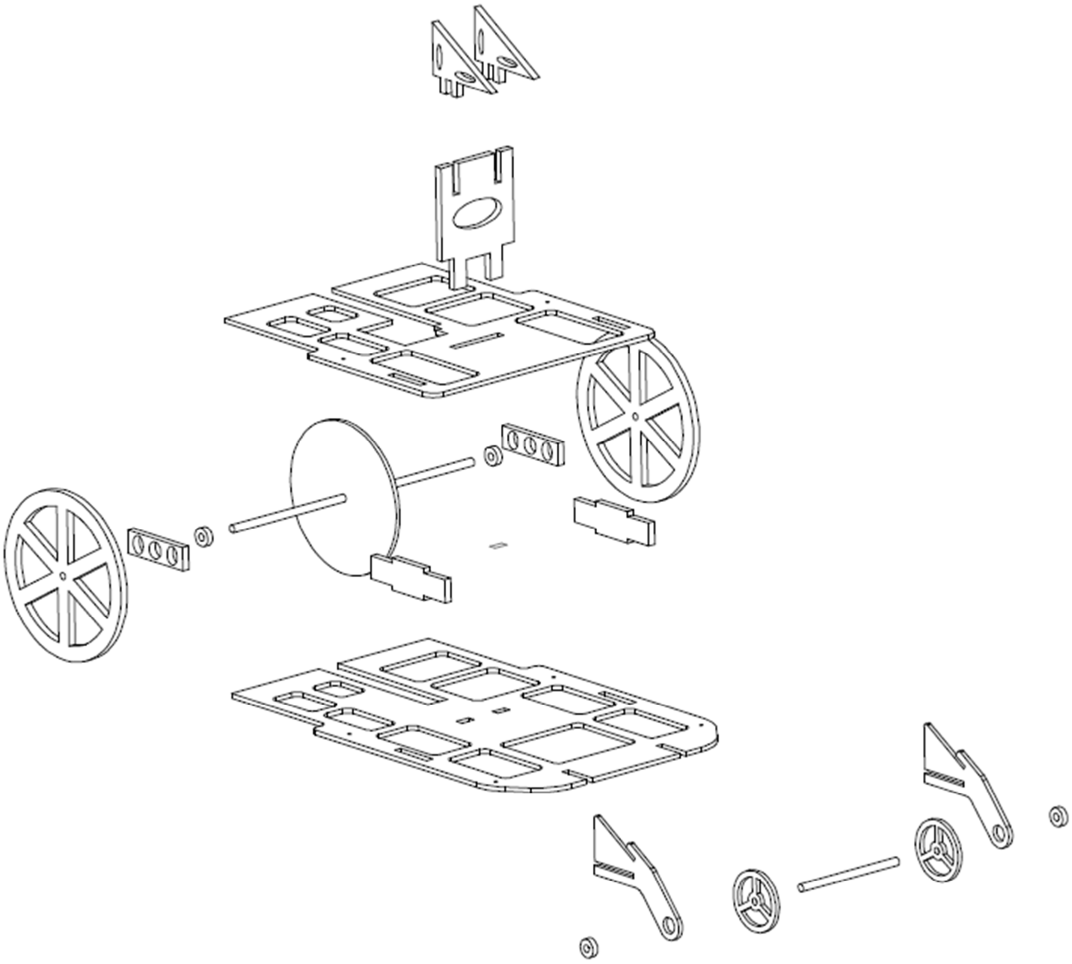


Figure 47: Exploded view of the SSV

1.3.4 Exercise about the impulse of the SSV on the wall

Given + Wanted:

Your SSV collides with the side of the track on the flat part at maximum speed under an angle
of 10°.

a) What is the impulse, if you assume an elastic collision?

b) How long does the collision need to last for the force to remain below 10 N?

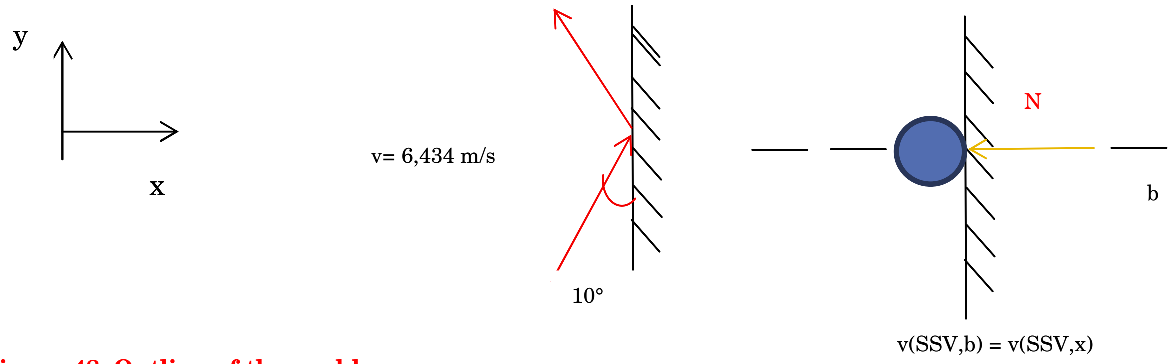


Figure 48: Outline of the problem

Solution:

a) v(max) = v(SSV,b) = 6,434$\frac{m}{s}$ (See Sankey diagram for solution)

- e =- $\frac{v\prime(wall,b)-v\prime(SSV,b)}{v(wall,b)-v(SSV,b)}$ = 1

with v(wall, b) = v'(wall,b) = 0

v'(SSV,b) = -v(SSV,b)

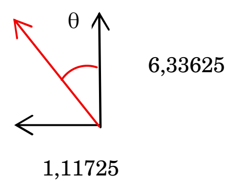
v(SSV,b)= 6,434 sin 10° = 1,11725 $\frac{m}{s}$

v'(SSV,b) = -1,11725 $\frac{m}{s}$

- o <Fy> during the collision = 0 ➔ Ly = Ly'

With L(y) = 0,9 * 6,434*cos(10°) = 0,9 * v(y)'

L(y) = 5,703 Ns



v(y) = v(y)' = 6,33623 m/s

After collision : tan θ = $\frac{1{,}11725}{6{,}33625}$ ➔ θ = 10°

b) Impact in the x-direction :

- $\int_{t1}^{t2} < N > * \, dt = L(2,x) - L(1,x)$

$with < N > \max = \; -10N$

L(2,x) = m* v(y)' = 0,9 kg * (-1,11725$\frac{m}{s}$)

L(1,x) = m* v(y) = 0,9 kg * 1,11725$\frac{m}{s}$

<N>(max) * (t2-t1) = 0,9*(-1,11725) – 0,9 * 1,11725

(t2 – t1) = 2,01Ns *$\frac{1}{10\,N}$

(t2-t1) = 0,2 seconds

If t1 = 0 seconds then the collision will last 0,2 seconds.

1.3.5 Exercise cyclist

Given + Wanted:

A cyclist is riding at a speed of 50 km/h. He arrives at a crossroad and needs to turn left. The radius of the turn is 10 m.

a) What is the necessary inclination angle? Does he have to reduce his speed to make a safe turn?
b) What is the maximum possible speed?

Mass of the cyclist: 60 kg; mass of the bicycle: 12 kg; distance between ground and center of gravity: 1,5 m (when he is riding vertically); Static coefficient of friction between wheels and ground: 0,3.

Solution:

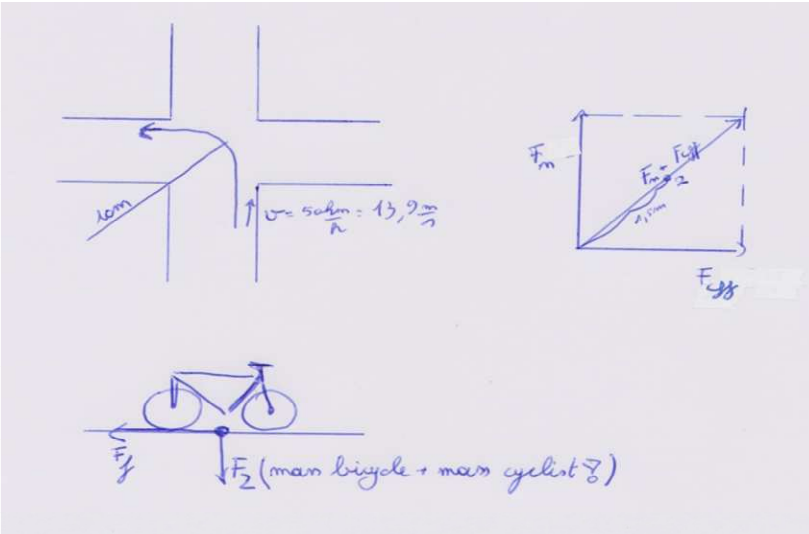


Figure 49: Outline of the problem

50km/h = $50*10^3/3600$ = 13,9 $\frac{m}{s}$

Total mass = mass of the cyclist + mass of the bicycle= 60 kg + 12 kg

F(cff)= centrifugal forces

F(f) = friction force

F(n) = normal force

F(g) = gravity force

a)

- F(cff) = $\frac{m*v^2}{r}$

  F(f) = F(cff)= $\frac{m*v^2}{r} = \frac{72\ kg*(13,9\frac{m}{s})^2}{10\ m}$ = 1391,1N
- F(n) = F(g) = m*g = 72 kg * 9,81 $\frac{N}{kg}$ = 706N
- tan(α) = $\frac{F(n)}{F(f)} = \frac{706\ N}{1391,1N}$ = 0,51
  - ***α = 26,9***

The cyclist will need an angle of 26,9°. But see the problem with the speed in (b).

b)

- F(f) = μ * m * g = 0,3 * 72 kg * 9,81 $\frac{N}{kg}$ = 212N = F(f,max)
- F(f) = F(cff) = $\frac{m*v^2}{r}$ ➔ v^2 = $\frac{F(f,max)*r}{m}$ = $\frac{212N*10m}{72\ kg}$ ➔ **v = 5,43 $\frac{m}{s}$ = 19,5 $\frac{km}{h}$**

The cyclist cannot take the turn with a speed of 13,9 m/s or 50 km/h. The maximum speed should be limited to 5,43 m/s or 19,5 m/s.

- tan(α) = $\frac{F(n)}{F(f,max)}$ = $\frac{706\ N}{212\ N}$ = 3,33 ➔ α = 73,3°

He will need an angle of 73,3°.

2 Enterprising

Link to the Wikipage of LOUIS XIV:

http://en.wikiversity.org/wiki/Engineering_Experience_4:_Design_a_Small_Solar_Vehicle/Nl/2013:_Team_PM9

3 Educating

3.1 Cooperation Contract

3.1.1 Description Project and Company

In Engineering Experience 4, six students of Group T, the International Engineering College in Leuven, team up to make a SSV or a Small Solar Vehicle that is able to participate in a race. The purpose of this project is that the students should gain experience in a real life assignment and therefore they have to follow a certain production path. After an elaborate orienting and analysis phase, follows the execution phase. This phase consists of three blocks: an Engineering, an Enterprising and an Education part. The Engineering part handles three report cases which include the design, building and simulating of the vehicle, while the enterprising and education part focuses on the promotion and informing on a web page and collecting all sorts of information in a final process report.

To enlarge the feeling of a real life situation, the team will work together as a virtual company. We have chosen our company name "Louis XIV" or in French "Louis Quatorze". This refers to the well-known monarch of France who reigned over 72 years in the 17th and 18th century. The French often call him the Roi-Soleil or Sun King. Here we find the connection between our company and our Solar Vehicle. We want to provide our customers with a durable, innovative and progressive solution. Our company is driven to be the best in its branch, just like the Sun King once said: L'état, c'est moi or in English: The state, that's me. We want to use this to promote the idea that the best solution, that's our solution.

3.1.2 Team Members

- Arne Claes

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Phone number: 0472/30.4753

Group: 210

- Alexander De Baere

Mail: alexander.de.baere@student.groept.be

Phone number: 0494/70.6236

Group: 210

- Bram Dezwart

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Phone number: 0494/84.6521

Group: 110

- Glen Pelgrims

Mail: glen.pelgrims@student.groept.be

Phone number: 0472/45.5241

Group: 210

- Ellen Van Dievel

Mail: ellen.van.dievel@student.groept.be

Phone number: 0479/58.2269

Group: 210

- Inge Van Mieghem **(Team leader)**

Mail: inge.van.mieghem@student.groept.be

Phone number: 0474/77.0751

Group: 210

3.1.3 Engagements

By accepting and respecting these engagements we, team Louis XIV, shall be able to point out both ourselves and our colleagues on our duties and expectations towards our team. They will act in the form of a small constitution and a way of thinking of our little company.

Art.1: Every week the team meets to discuss the recently events and future assignments. The team leader will notice the other team members in advance on the time and place of these meetings. The notary makes a small report on every meeting.

Art.2: Every form of absence should be notified to the team leader before the meeting starts and should have a decent explanation.

Art.3: The team has to comply with each deadline on time. The team members must regularly check the communication channels the hours up to the submission so late emergencies can be avoided.

Art.4: Each member comes prepared to the team meeting in order that valuable time does not go wasted.

Art.5: The members keep the team leader updated on the status of their work so immediate action can be undertaken in case of encountering problems and the team leader is able to keep an overview over the entire project.

Art.6: During the project, the members are expected to check daily the different communication channels like the Facebook page, the Wikiversity page, e-mail, Toledo and off course their cellphones.

Art.7: Everybody respects everybody.

Art.8: All the materials and machines are used properly according to their manual and with respect.

Art.9: It's expected of the entire team to perform as best as they can, so it's possible to achieve a very fast and innovative SSV.

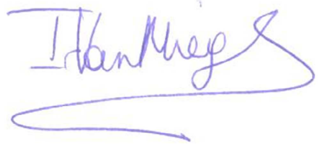
Art.10: Every document for a deadline has to be corrected by at least one other team member to correct quality, style and spelling.

Art.11: Veto is entitled to Gods, not to a team leader. In case of a vote and the votes are equal, the team leader has the decisive vote.

I have read these conditions and agree to devote myself to project Louis XIV.

Team

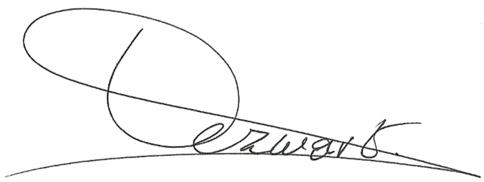
Leader, Inge Van Mieghem;



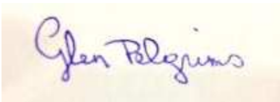
Arne Claes;

Alexander De Baere;

Bram Dezwart;



Glen Pelgrims;



Ellen Van Dievel.

3.2 Plan Of Approach(PVA)

3.2.1 Introduction

This document shows a short introduction of the assignment. Why we do the assignment and how we will bring it to a good and as a team.

3.2.1.1 Approvement and correction

Our coach, Hu Yunhao, will guide our team through this project. He will help us work as a team and improve our cooperation process. He will evaluate and give feedback on how we work as a team. He is also the one who will judge our reports and our individual contribution to the project.

During this project most likely problems will occur. We have to keep in mind that our coach will not just hand over the solutions we need. This means we have to find all the information and solutions ourselves. Our coach's role is merely to assist us during this search and guide us in the right direction.

3.2.1.2 Explanation plan of approach

To finally come to our solar car, we have to look at three phases: oriental phase, analysis phase and the implementation. The oriental phase consists out of our cooperation contract. The analysis phase consists out of three topics: the plan of approach, the work breakdown structure and Gantt Chart. The implementation is the most important part

of the entire project because it consists out of three topics: engineering, enterprising and educating. In the engineering topics there are three cases our team has to complete: Case SSV part 1, Case Simulink and Case SSV part 2. In the educating topic we have to make a wikipage and engrave our logo on the solar car.

To finalize our project we will divide all the subjects above. Arne Claes will keep an eye on the administration (oriental phase and the analysis phase). For the implementation phase, the engineering part will be the responsibility of the team leader Inge Van Mieghem, the enterprising part will be the responsibility of Bram Dezwart and the educating part will be the responsibility of Ellen Van Dievel. When problems occur they'll inform the team leader. The team leader at his turn will plan a new meeting to discuss the problem. When we encounter difficulties solving the problem we will ask for guidance from the coach. The information about the project will be giving during the seminaries in the first weeks.

3.2.2 Project description

At the end of the project the SSV must be capable of finishing a race and compete with other SSV models. At the end of the project we would have gathered a basic understanding on how the SSV works, the design, the different analysis, the use of Matlab, Wikipage, etc. The cases and the final process report are the important subjects of the project.

Every team member will participate as much as possible with all the subjects (Engineering, Enterprising and Educating). The members responsible for the different subjects always have to inform the others about everything that happened in the past week during the weekly meetings. Afterwards every team member must be capable of understanding and explaining every subject.

3.2.2.1 Client

Our client is the Umicore Solar Team. They want to build a solar car but they want to keep the budget low for building the solar car, they want to present a miniature model of the car on the market. They ask us, an engineering bureau, to give a solution. We have to make a demo model of a SSV (Small Solar Vehicle) without a battery package. Our team will then predict and optimize the behavior of the model and study the energetic level.

3.2.2.2 Team

Our team, LOUIS XIV, consists of six team members: Arne Claes, Alexander De Baere, Bram Dezwart, Glen Pelgrims, Ellen Van Dievel and Inge Van Mieghem.

3.2.2.3 Beginsituation and backgrounds

We are an engineering bureau and we have to give a solution to the contractor, the Umicore Solar Team, to build a demo model. At the beginning we receive a DC-motor and a panel with solar cells.

3.2.2.4 Target
LOUIS XIV wants to develop the most innovative car. We will focus on creating a vehicle using innovative techniques, methods and materials that will benefit the performance of our solar car. Indirectly our goal is to win the race.

3.2.2.5 Problems
The information about the SSV will be given during the seminars. During those seminars we have the possibility to ask questions related to our own SSV model. Afterwards we can find more information on the Internet or go to the library.

First problem we have to fix are the problems with Toledo because not every one of the team has already all the information about EE4.

More problems can occur during the project. We will have to reach our deadlines in time. The deadlines we set in our Gantt Chart must be respected. If there are any changes we will have to change other deadlines and this could lead to a domino effect. If one team member senses that he or she won't be able to reach the deadline, other team members will be there to intervene.

The beginning isn't always the easiest part but once we have an idea of the model of the SSV everything should go like planned. If there are problems concerning cooperation of the team, our coach, Hu Yunhao, will be there to help us.

3.2.2.6 Expected result
The expected result is to successfully complete the different phases of the project: The oriental phase (cooperation contract), the analysis phase (Plan of approach, WBS and Gantt Chart), Implementation phase (engineering, enterprising and educating). Finally we want to finish and win the race.

In week 6 (22th of March) Case SSV part 1 must be handed in together with the first version of the Process Report online. In week 11 (10th of May) Case SSV part 2 and the Final Process Report must be handed in. We will also be tested twice during this project. The tests will evaluate the material seen during the seminaries.

3.3 Work Breakdown Structure (WBS) and Gantt Chart

3.3.1 WBS

See 3.3.5 Literature appendix (X).

3.3.2 Gantt Chart

See 3.3.5 Literature appendix (X).

3.4 Blog and meetings

Each week a short report will be uploaded to our Wikipage. This gives you, the reader, the possibility to follow the progression of our project.

Week 1

This week an introduction seminar was given about the Small Solar Vehicle (SSV) project. The goals of the project were explained briefly. The racetrack is going to be 14m long, including a slope of 4m. Our SSV is also limited to a minimum weight of 0,750 kg. We named our team “LOUIS XIV” after the French king “Louis the 14th“ who was nicknamed ‘the Solar King’. We divided the team functions among the team members and told each other about our individual vision on the project.

- *Deadlines*: Friday 15/02 18h00: “Analysis Phase”: Cooperation contract, WBS, Plan of Approach and Gantt Chart.

- *Seminar*: Introduction

Week 2

This week’s seminar was about the solar panel en the DC motor that we have to implement in our SSV. After the seminar, we went to the lab to determine the characteristics of the solar panel. Using our measurements we were able to calculate the diode factor, which we will need in further calculations. There also was a feedback session with our coach. He told us the “Analysis Phase” was approved, however we had to make small changes to the Gantt Chart concerning a more efficient spread of the deadlines we set up. Also the Work Breakdown Structure has to be a little more specific.

- *Deadlines*: Test (Toledo) about solar panel and DC motor

- *Seminar*: Solar panel and DC motor

Week 3

This week there was a seminar about the race strategy and gear ratio. We received the specifications for the next deadline in week 6: SSV Case 1. We divided the work. One part of the team is going to do research about the design

and steering of the SSV and the others are going to calculate different gear ratios.

- *Deadlines*: /

- *Seminar*: Race strategy and gear ratio

Week 4

A seminar about Matlab and Simulink was given. We decided we aren't going to use radio controlled steering. We are going to make a mechanism to minimize friction when our SSV collides with the sidewall. A prototype will be drawn using the technical drawing program Solid Work. Last week the gear ratios couldn't be calculated because some parameters were still undetermined. After finishing the gear ratio calculations we are going to try to do some calculations with Matlab and draw the circuit of our SSV in Simulink. This is of great importance because we'll need the circuit to make calculations in week 5.

- *Deadlines*: /

- *Seminar*: Matlab and Simulink

Week 5

This week we were still working towards the deadline of next week. The Simulink part didn't go as planned and there are still some faults in the Matlab calculations. We split up the team so one half could focus on the simulations and the others were going to make the body of the SSV in Fablab. The material we wanted to use wasn't available in Fablab. The 3mm PMMA sheets weren't delivered in time due to bad weather (snowfall). That part of the team then started focusing on the numerical calculations for Case one.

- *Deadlines*: /

- *Seminar*: Fablab

Week 6

This week we had to hand in the first Case. We had already done a lot of work on this case, but there was still a lot of fine-tuning to do. The Matlab part and the numerical calculations were finished by the beginning of the week. However with the Simulink part we encountered some problems. Some of them were solved in time. Others weren't so easy to figure out. In the end the part where we had to simulate the race didn't give us reliable information, we encountered a fault that we couldn't solve.

- *Deadlines*: Friday 22-03, hand in Case SSV part 1 and Simulink

Friday 22-03, fill in Peer Assessment 1

- *Seminar*: /

<u>Week 7</u>

Last week we handed in the first Case. This week we presented the work we individually did to the other members of the team. We looked up what we are supposed to do in the second case. We divided the work of the next case. We discussed and adjusted the frame of the SSV.

- *Deadlines*: /

- *Seminar*: /

<u>Week 8</u>

This week we printed and assembled our SSV prototype. We cut the gears using the laser cutter and installed everything on the frame. We encountered some problems concerning the movement of the wheels. The body didn't have sufficient space for the wheels to turn freely. We made some drastic cuts in the body the enable our SSV to be ready for the test run next week.

- *Deadlines*: Tuesday 16-04, test about Case one.

Tuesday 23-04, test run SSV

<u>Week 9</u>

In the beginning of the week we tested our SSV on the racetrack using battery power. It seemed that our frame was solid enough. However we concluded we could do some serious downscaling of the SSV and saves up on a lot of weight. We concluded that a collision near the front of the SVV is almost impossible on the track. The gears didn't work as expected. The SVV wouldn't start as fast as calculated. The reason for this was that we only used two gears because the third one was broken during assembly. The resulting driven gear was also a bit deformed because it was heated too much during assembly. During the week we made drastic adjustments on the frame and body of the car. We cut it again and the result is satisfying. We managed to save up on a lot of weight as expected. The body is even more solid and impact proof than the former one. The double frame is smaller in height and looks more attractive. We however are concerned about the gears. We cut out new gears and we hope these will work as expected. At the beginning of next week we expect the assembly to be finished.

- *Deadlines*: Tuesday 23-04, test run SSV

Week 10

This week we finished the assembly of the final SSV. We did a test run on the track. Everything worked as expected. Except the gears have more friction than first expected. During the week we worked on the second part of the case. The end of the project is nearing. We look forward to the day of the race.

- *Deadlines*: Tuesday 07-05, Show SSV

Week 11

This week we showed the SSV to the jury. We got third price in the category "design". We were really satisfied about this price. The rest of the week we worked on the final report of the project, which had to be handed in at Friday. The only thing that we have to do is race. We are looking forward to it.

- *Deadlines*: Friday 10-05, hand in final report

Meeting report n° 1

Attendance

Name	Function
Inge Van Mieghem	president
Arne Claes	secretary
Bram Dezwart	
Ellen Van Dievel	
Alexander De Baere	
Glen Pelgrims	

Agenda

Topics to be discussed:

- Introduction
- Task division
- Analysis phase

Approval

- /

Task list and follow up

	Assignment	Team members	Due date	Done (Y/N)	Actual work-load (h)
	Work Breakdown Structure	Ellen	19-02		
	Gantt Chart	Glen	19-02		
	Cooperation Contract	Alexander	19-02		
	Plan of Approach	Inge	19-02		
	Meeting report + blog	Arne	19-02		
	Check reports	All	19-02		
	Create Dropbox and Facebook group	Inge	14-02		
	Create Wikipage	Bram	14-02		

Agenda discussion

- Introduction

We introduced ourselves to the other team members. We had just been given an introduction seminar about to SSV project. We explained what we individually expected from the project and from the solar vehicle we are going to build. By doing so, we got more insight on each other's point of view.

- Task Division

We divided the mayor team tasks. Inge is going to be the project leader. Arne will be responsible for the administration (meeting reports, dropbox, blog reports, etc…). Bram will be the one in charge of the Wikipage. It is his task to update the page frequently. The other members of the team don't have a specific task. Team leader Inge will create a Facebook group and a shared

dropbox folder. Bram will create a Wikipage before the next meeting. Arne will write a meeting report and blog after the week has ended.

- Analysis Phase

The first deadline of the project is to make a WBS, Gantt Chart, Cooperation contract and Plan of Approach. This is called 'the Analysis Phase'. We brainstormed about the WBS. Ellen will make a digital version of the WBS and Glenn will use the WBS to create a Gantt Chart. Inge is going to make a Plan of Approach and Alexander will write a cooperation Contract. Everybody has to re-read the written articles to check if the content is correct.

Future Meeting:

Next meeting: 20-02-2013

Location: GroupT

Meeting report n° 2

Attendance

Name	**Function**
Inge Van Mieghem	president
Arne Claes	secretary
Bram Dezwart	
Ellen Van Dievel	
Alexander De Baere	
Glen Pelgrims	

Agenda

Topics to be discussed:

- Discus the design of the SSV
- Discus characteristic measurements

Approval

- Analysis Phase

Task list and follow up

	Assignment	Team members	Due date	Done (Y/N)	Actual work-load (h)
	Work Breakdown Structure	Ellen	19-02	Y	1
	Gantt Chart	Glen	19-02	Y	1,5
	Cooperation Contract	Alexander	19-02	Y	1,5
	Plan of Approach	Inge	19-02	Y	2
	Meeting report + blog	Arne	19-02	Y	1
	Check reports	All	19-02	Y	1
	Create Dropbox and Facebook group	Inge	14-02	Y	0,5

	Create Wikipage	Bram	14-02	Y	1,5
	!!Test Toledo (Solar panel + DC motor)!!	All	22-02	Y	
	Update WBS	Ellen	26-02		
	Update Gantt Chart	Glen	26-02		
	Calculate Diode factor	Inge	26-02		
	Draw DC-motor in Solid Works	Alexander	26-02		
	Meeting report + blog	Arne	26-02		

Approval

- Analysis Phase

The majority of the articles from the Analysis Phase were approved by our coach. Only the WBS and the Gantt Chart have to be slightly adjusted. The deadlines on the Gantt Chart are not evenly spread along the project. The WBS has to be a little bit more detailed. Glenn is going to make adjustments to the Gantt Chart and Ellen will adjust the WBS.

Agenda discussion

- Discus the design of the SSV

During the second seminar we got more information about the solar panel and DC motor. We were told we have to complete a test on Toledo. Afterwards we held a discussion about the design of the SSV. We did not get any wiser. We decided we did not have sufficient information for the design yet.

- Discus characteristic measurements

In the lab we did some measurements to sort out the diode factor of the solar panel. We put the results of the measurements in graphs. Inge is going to calculate the diode factor of the solar panel.

Future Meeting:

Next meeting: 26-02-2013

Location: GroupT

Meeting report n° 3

Attendance

Name	Function
Inge Van Mieghem	president
Arne Claes	secretary
Bram Dezwart	
Ellen Van Dievel	
Alexander De Baere	
Glen Pelgrims	

Agenda

Topics to be discussed:

- Discus the design of the SSV
- Case SSV Part 1

Approval

- Diode factor

Task list and follow up

	Assignment	Team members	Due date	Done (Y/N)	Actual work-load (h)
	!!Test Toledo (Solar panel + DC motor)!!	All	22-02	Y	/
	Update WBS	Ellen	26-02	Y	0,5
	Update Gantt Chart	Glen	26-02	Y	0,5
	Calculate Diode factor	Inge	26-02	Y	1
	Draw DC-motor in Solid Works	Alexander	26-02	Y	1,5
	Meeting report + blog	Arne	26-02	Y	1
	Search design SSV (Part 1)	Alexander	05-03		
		Arne	05-03		
		Bram	05-03		
	Meeting report + blog	Arne	05-03		
	Calculate gear ratio's	Inge	12-03		
		Ellen	12-03		
		Glenn	12-03		

Approval

- Diode Factor

Inge calculated the Diode Factor of the solar panel using the measurements of last week. The result is a factor of 1,23. This is an acceptable value for the diode factor. Some of the team members checked the equation and approved the factor.

Agenda discussion

- Discus the design of the SSV

During the third seminar we got more information about the race strategy and the transmission of the SSV. Again, we held a discussion about the design of the car. Because we had more information we decided to build a three-wheel car with a radio controlled front wheel. Choosing this design we will avoid collision with the walls. We are going to use the steering mechanism from a toy car. If this design doesn't work or fails, we will make a four-wheel car with guiding wheels at the side. So when the car collides, it doesn't stop abruptly. Arne, Alexander and Bram are going to make a prototype of the first model of the car.

- Case SSV part 1

We discussed what tasks we have to do before the next deadline. The first task is to design the SSV. The second is to calculate the best gear ratio. The third is to calculate with numerical method. And the fourth task is making a Sankey diagram of our SSV. We already divided the first two tasks. Arne, Alexander and Bram are going to take care of the design. Inge, Ellen and Glenn are going to calculate the gear ratios.

Future Meeting:

Next meeting: 05-03-2013

Location: Group T

Meeting report n° 4

Attendance

Name	**Function**
Inge Van Mieghem	president
Arne Claes	secretary
Bram Dezwart	
Ellen Van Dievel	
Alexander De Baere	
Glen Pelgrims	

Agenda

Topics to be discussed:

- Discus the design of the SSV part 2
- Gear ratio
- Matlab and Simulink

Approval

- /

Task list and follow up

	Assignment	Team members	Due date	Done (Y/N)	Actual work-load (h)
	Search design SSV (Part 1)	Alexander	05-03	Y	1
		Arne	05-03	Y	1
		Bram	05-03	Y	0,5
	Meeting report + blog	Arne	05-03	Y	1
	Calculate gear ratio's	Inge	12-03		
		Ellen	12-03		
		Glen	12-03		
	Build Simulink circuit	Inge	12-03		
		Ellen	12-03		
		Glen	12-03		
	Design the SSV + draw prototype in SW	Alexander	12-03		
		Bram	12-03		
	Design the SSV	Arne	12-03		
	Meeting report + blog	Arne	12-03		
	Start writing report on Case 1	Arne	19-03		

Approval

/

Agenda discussion

- Discus the design of the SSV part 2

Again, we held a discussion about the design of the car. Because no team member has a radio controlled toy car, we decided to step off of the idea of a radio controlled front wheel. Another reason was because buying a new RC car would be too expensive. We finally decided to build a four wheel car. Each of the wheels is going to have a 5cm radius. To prevent our car from stopping after colliding with the wall, we are going to implement guiding wheels at the side of our frame. We hope this might reduce friction so our car doesn't stop after collision.

- Gear Ratio

For calculations of the gear ratio, some parameters (#wheels, wheel radius, etc…) still have to be determined. Now we decided a final design the calculations of the ratio can be finished.

- Matlab and Simulink

This week's seminar was about Matlab and Simulink. Inge, Ellen and Glen are going to try to build the electric circuit of the car in Simulink while the others are focusing on the built of the car.

Future Meeting:

Next meeting: 12-03-2013

Location: Group T

Meeting report n° 5

Attendance

Name	**Function**
Inge Van Mieghem	president
Arne Claes	secretary
Bram Dezwart	
Ellen Van Dievel	
Alexander De Baere	
Glen Pelgrims	

Agenda

Topics to be discussed:

- Building the SSV
- Case SSV part 1, Matlab and Simulink
- Numerical calculations

Approval

- Gear ratio

Task list and follow up

	Assignment	Team members	Due date	Done (Y/N)	Actual work-load (h)
	Calculate gear ratio's	Inge	12-03	Y	1
		Ellen	12-03	Y	0,5
		Glen	12-03	Y	0
	Build Simulink circuit	Inge	12-03	Y	1,5
		Ellen	12-03	Y	1,5
		Glen	12-03	Y	22,5
	Design the SSV + draw prototype in SW	Alexander	12-03	Y	5
		Bram	12-03	Y	1,5
	Design the SSV	Arne	12-03	Y	6
	Meeting report + blog	Arne	12-03	Y	1
	Building SSV part 1	Alexander	19-03		
		Arne	19-03		
		Bram	19-03		

	Deadline Case SSV part 1	Alexander	22-03		
		Arne			
		Bram			
		Ellen			
		Glen			
		Inge			

Approval

The decision to work with a gear ratio of 10 was approved by all team members. The prototype of the body is also approved.

Agenda discussion

- Building the SSV

It about time we start building the SSV. Arne, Alexander and Bram are going to the Fablab to cut the body out of PMMA.

- Case SSV part 1, Matlab and Simulink

The Matlab calculations are going well. Only the Simulink part doesn't go as smooth as hoped. Glen will focus on the Simulink program and try to debug it.

- Numerical calculations

Arne and Bram are going to do the numerical calculations for question 3 of the Case. They'll use Maple to do the calculations to obtain the graphs of the displacement and speed of the SSV during the first time-second of the race. Alexander will be responsible for making the Sankey diagram.

Future Meeting:

Next meeting: 19-03-2013

Location: Group T

Meeting report n° 6

Attendance

Name	Function
Inge Van Mieghem	president
Arne Claes	secretary
Bram Dezwart	
Ellen Van Dievel	
Alexander De Baere	
Glen Pelgrims	

Agenda

Topics to be discussed:

- Case SSV part 1

Approval

- /

Task list and follow up

	Assignment	Team members	Due date	Done (Y/N)	Actual work-load (h)
	Building SSV part 1	Alexander	19-03	N	7
		Arne	19-03	N	7
		Bram	19-03	N	7
	Deadline Case SSV part 1	Alexander	22-03		
		Arne			
		Bram			
		Ellen			
		Glen			
		Inge			

Approval

Fablab didn't have 3mm PMMA anymore. The material will be delivered at the end of the week. The delivery was postponed because of bad weather (heavy snowfall).

Agenda discussion

- Case SSV part 1

This week we will finish the first part of the SSV case. The report has to be made and handed in at Friday 12 'o clock.

Future Meeting:

Next meeting: 26-03-2013

Location: Group T

Meeting report n° 7

Attendance

Name	Function
Inge Van Mieghem	president
Arne Claes	secretary
Bram Dezwart	
Ellen Van Dievel	

Alexander De Baere
Glen Pelgrims

Agenda

Topics to be discussed:

- Case SSV part 2

Approval

- /

Task list and follow up

	Assignment	Team members	Due date	Done (Y/N)	Actual work-load (h)
	Assembly in Solid Works	Alexander	16-04		
		Bram	16-04		
	Fablab prototyping	Arne	16-04		
		Alexander	16-04		
	Preparing Case 2 exercise	Inge	16-04		

Approval

/

Agenda discussion

- Case SSV part 2

This week each member presented his part of the first case to the others. We also looked up what is expected in the next case. We divided most of the tasks. The prototype is ready to be built. Alexander and Bram are going to make the assembly of the SSV using a technical drawing program. Inge is going to prepare the exercise given in case 2.

Future Meeting:

Next meeting: 16-04-2013

Location: Group T

Meeting report n° 8

Attendance

Name	Function
Inge Van Mieghem	president
Arne Claes	secretary
Bram Dezwart	
Ellen Van Dievel	
Alexander De Baere	
Glen Pelgrims	

Agenda

Topics to be discussed:

- The assembly in Solid Works + Laser cutting
- Assembly of the SSV prototype

Approval

- /

Task list and follow up

	Assignment	Team members	Due date	Done (Y/N)	Actual work-load (h)
	Assembly in Solid Works	Alexander	16-04	Y	1
		Bram	16-04	Y	4
	Fablab Laser cutting	Arne	16-04	N	/
		Alexander	16-04	N	/
	Preparing Case 2 exercise	Inge	16-04	Y	1
	Fablab Laser cutting	Bram	19-04		
		Inge	19-04		2
		Ellen	19-04		
		Glen	19-04		2
	Assembly body	Arne	22-04		
	Assembly driving shafts	Bram	22-04		
	Assembly whole SSV prototype	Arne	23-04		
		Bram	23-04		
		Alexander	23-04		
	Test run SSV		23-04		

Approval

Fablab wasn't available when we went during Easter holiday.

Agenda discussion

- Case SSV part 2 The assembly in Solid Works + Laser cutting

The assembly in Solid Works has been done nicely. The parts are ready to be cut using the laser cutter. Inge, Bram, Ellen and Glen are going to go to Fablab to cut out the parts.

- Assembly of the SSV prototype

During the weekend Arne is going to glue the essential parts to the frame and Bram is going to assemble the driving shaft. Arne, Bram and Alexander are going to assemble the whole SSV after the weekend so the prototype is ready for the test run on Tuesday.

Future Meeting:

Next meeting: 23-04-2013

Location: Group T

Meeting report n° 9

Attendance

Name	**Function**
Inge Van Mieghem	president
Arne Claes	secretary
Bram Dezwart	
Ellen Van Dievel	
Alexander De Baere	
Glen Pelgrims	

Agenda

Topics to be discussed:

- The performance during test run
- Adjustments on the prototype

Task list and follow up

	Assignment	Team members	Due date	Done (Y/N)	Actual work-load (h)
	Fablab Laser cutting	Bram	19-04	Y	2
		Inge	19-04	Y	2
		Ellen	19-04	Y	2
		Glen	19-04	Y	2
	Assembly body	Arne	22-04	Y	1
	Assembly driving shafts	Bram	22-04	Y	2
	Assembly whole SSV prototype	Arne	23-04	Y	5
		Bram	23-04	Y	5
		Alexander	23-04	Y	5
	Test run SSV		23-04	Y	
	Adjust prototype in Solid works	Inge	24-04		
		Bram	24-04		
		Alexander	24-04		
		Arne	24-04		
		Ellen	24-04		
		Glen	24-04		
	Fablab cutting parts	Inge	25-04		
		Glen	25-04		
		Ellen	25-04		
	Glue the first frame	Arne	26-04		
	Assemble the driving shaft	Bram	29-04		

Approval

The assembly of the prototype was difficult. We encountered a lot of problems with the body. These problems have to be solved when adjusting the body.

Agenda discussion

- The performance during test run

We tested our SSV on the racetrack using battery power. It seemed that our frame was solid enough. However we concluded we could do some serious downscaling of the SSV and save up on a lot of weight. We concluded that a collision near the front of the SVV is almost impossible on the track. The gears didn't work as expected. The SVV wouldn't start as fast as calculated. The reason for this was that we only used two gears because the third one was broken during assembly. The resulting driven gear was also a bit deformed because it was heated too much during assembly.

- Adjustments on the prototype

We are going to make drastic adjustments on the frame and body of the car. We will cut it again in Fablab. Our main focus is to save up on a lot of weight. The double frame will be made smaller in height. We'll cut out new gears and we hope these will work as expected. At the beginning of next week we expect the assembly to be finished.

Future Meeting:

Next meeting: 30-04-2013

Location: Group T

Meeting report n° 10

Attendance

Name	**Function**
Inge Van Mieghem	president
Arne Claes	secretary
Bram Dezwart	
Ellen Van Dievel	
Alexander De Baere	
Glen Pelgrims	

Agenda

Topics to be discussed:

- Test run with final SSV
- Discussing and dividing case 2

Task list and follow up

	Assignment	Team members	Due date	Done (Y/N)	Actual work-load (h)
	Adjust prototype in Solid works	Inge	24-04		7
		Bram	24-04		3
		Alexander	24-04		7
		Arne	24-04		4
		Ellen	24-04		2
		Glen	24-04		1
	Fablab cutting parts	Inge	25-04		2
		Glen	25-04		2
		Ellen	25-04		2
	Glue the first frame	Arne	26-04	Y	0,5
	Assemble the driving shaft	Bram	29-04		2
	Buying a switch	Arne	7-05		
		Bram	7-05		
	Improving Sankey Diagram	Alexander	7-05		
	Working on Case 2	Inge	7-05		
		Bram	7-05		
		Alexander	7-05		
		Arne	7-05		
		Ellen	7-05		
		Glen	7-05		
	Installing side wheels	Bram	7-05		
	Installing switch	Bram	7-05		
	Presenting the SSV to jury	All	7-05		

Approval

The final SSV is assembled and tested on the track.

Agenda discussion

- Test run with final SSV

We tested our final SSV model on the racetrack using battery power. Everything worked well. The guiding wheels weren't installed yet, but will be installed by next week.

- Discussing and dividing case 2

The theoretical part 2 of the project "case 2" was discussed and the work was divided. By next week we try to finish as much of the work as possible.

Future Meeting:

Next meeting: 7-05-2013

Location: Group T

Meeting report n° 11

Attendance

Name	Function
Inge Van Mieghem	president
Arne Claes	secretary
Bram Dezwart	
Ellen Van Dievel	
Alexander De Baere	
Glen Pelgrims	

Agenda

Topics to be discussed:

- Discussing case 2

Task list and follow up

	Assignment	Team members	Due date	Done (Y/N)	Actual work-load (h)
	Buying a switch	Arne	7-05	Y	1
		Bram	7-05	Y	1
	Improving Sankey Diagram	Alexander	7-05	Y	3
	Working on Case 2	Inge	7-05	Y	8
		Bram	7-05	Y	5
		Alexander	7-05	Y	5
		Arne	7-05	Y	
		Ellen	7-05	Y	3,5
		Glen	7-05	Y	
	Installing side wheels	Bram	7-05	Y	0,5
	Installing switch	Bram	7-05	Y	0,25
	Presenting the SSV to jury	All	7-05	Y	2
	Momentum's analysis	Arne	10-05		
		Inge	10-05		
	Sankey Diagram	Alexander	10-05		
	2D sketches	Ellen	10-05		
		Bram	10-05		
	Simulink adjustments	Glen	10-05		

Approval

We got the third price from the jury in the category "design". We are very pleased to receive this price! The test run of the SSV worked out fine!

Agenda discussion

- Discussing case 2

Last week we worked on the second case of the project. We are still working on it now. Some team members had still some remarks or questions. We tried to help each other out. The process of case 2 was evaluated. We are going to finish it before Friday.

Future Meeting:

Next meeting: Racing Day!

Location: Group T

3.5 Final report

3.5.1 Planning

The initial Gantt Chart differs from the final Gantt Chart due by changing tasks to the different team members and due to the time. In the beginning we had an idea of what all the cases included. But, after a while, we understood that it was less work than we thought. We had calculated around 120 hours for everyone to work on the project. But if

we look at the logs this is around 70 hours, 50 hours less then we calculated. But still 70 hours of work is a lot of workload.

We also changed a lot in our planning. In the Initial Gantt Chart there was given a certain responsibility to each team member of the group. But when the project continued these responsibilities weren't mostly the same as in the Gantt Chart. We assigned most of the work during the meetings. Every next meeting we checked of all the assigned work that was completed.

Every week the team leader had prepared what we had to discuss that week and what had to been done: for example reach deadlines, go to Fablab, discussing design … Every Tuesday afternoon we came together to discuss what everyone was doing and how well the tasks went. Then we saw who could do this in the appropriate time. The given time was always to the next meeting on Tuesday.

The first problem occurred with the Simulink case. For the third simulation of the Simulink case we had many problems with the presentation of the different graphs. The second problem we encountered happened with our first prototype of the SSV. The frame was not that very well designed to protect itself against collision. During the transport of the material most of the material was already broken. The day of the test drive we decided to make another prototype, which existed of a frame that could resist against many collisions. By the use of diffracted angles we could provide this protection.

But in general we didn't have many problems. If there were problems we discussed them briefly during our other courses.

3.5.2 Cooperation

In the pie charts below you can see the percentage workload from each member of the team spent on a particular part.

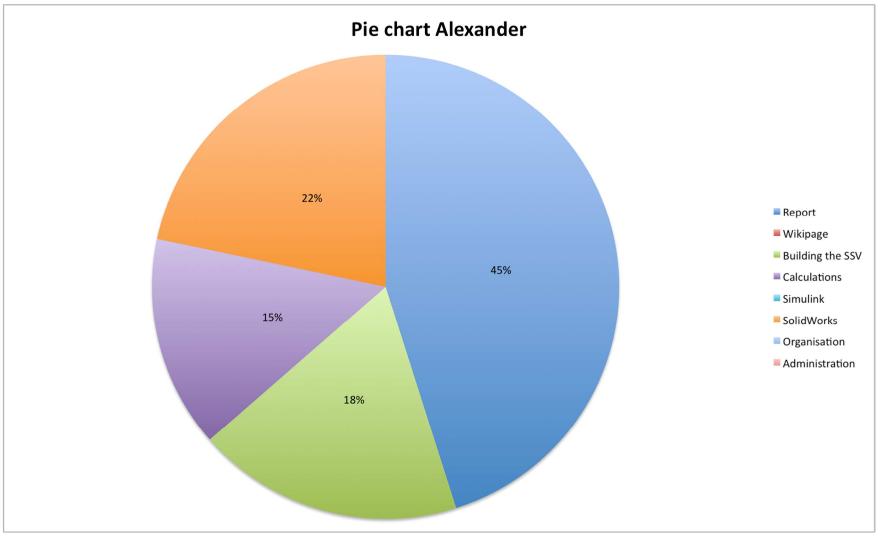


Figure 50: Pie chart Alexander

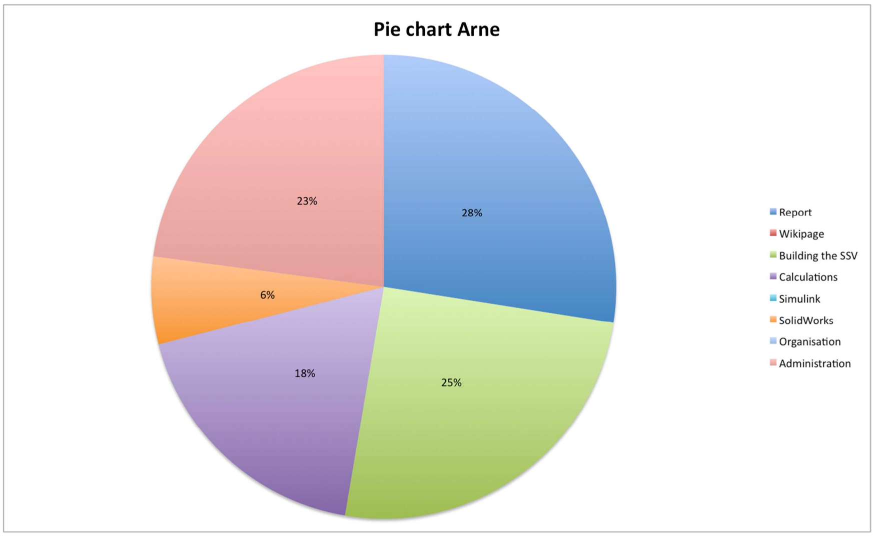


Figure 51: Pie chart Arne

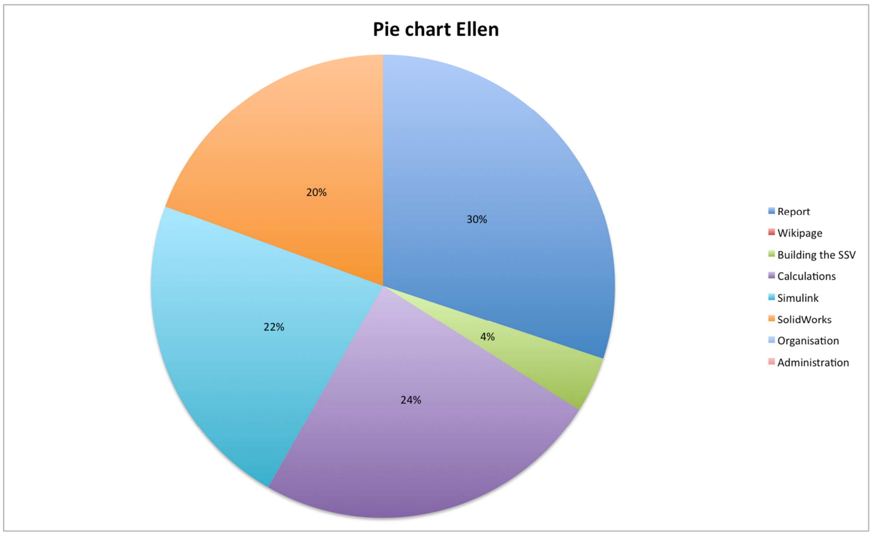


Figure 52: Pie chart Ellen

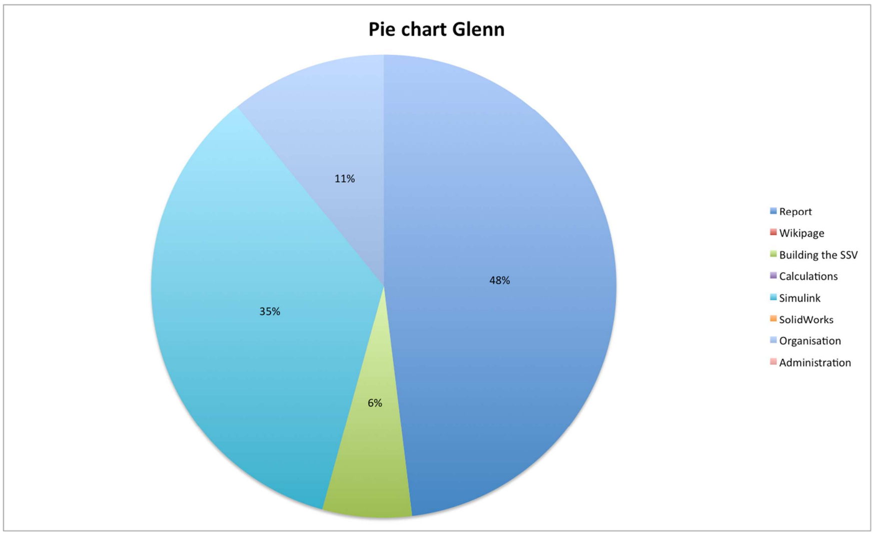


Figure 53: Pie chart Glen

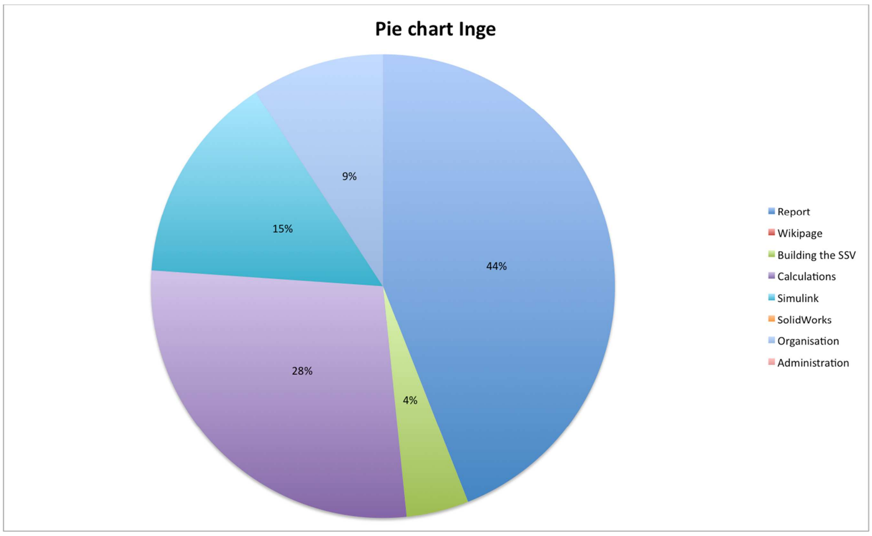


Figure 55: Pie chart Inge

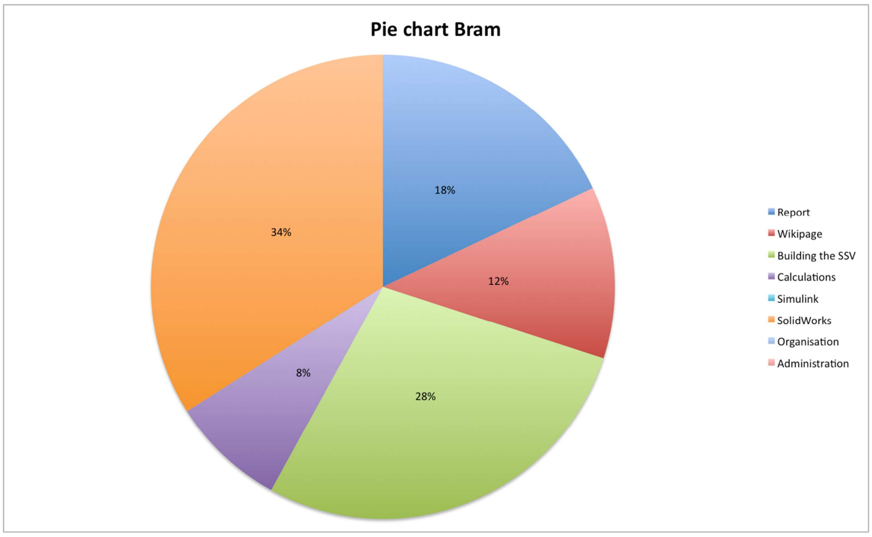


Figure 54: Pie chart Bram

3.5.3 Skills

In the beginning we had to see what every team member was capable of. This wasn't a very easy task. But when the project continued we saw a lot of skills from each team member. But we decided that everyone had to do a bit of every part because then every team member had a better view on the project. Our team exists of many different team members with different skills. We also divided the work like that.

The team leader understood after a while that without knowing what is going on in the whole project you also couldn't be a team leader. A team leader must be up to date with every little part that is going on otherwise there could develop problems like double work and misunderstandings. In this project there weren't many problems like this.

As a team we didn't have any skills that were insufficient. Everyone did their part of the project and together we had all the skills we needed for the project. Because of the fewer problems we had, we are all pleased by the result that we can give: a small, beautifully designed SSV that will try to win the race.

3.5.4 Conclusion

As a team we reached all our deadlines and most of our goals. For our goals we wanted to complete the different phases of the project (oriental, analysis and implementation phase) and we wanted to finish the race and win. The goal finishing and winning is still a surprise for us but we are sure the SSV will ride on the track. If we had problems with the group or with the project, they were solved in-group or we went to our coach Hu Yunhao who helped us a lot.

The report was handed in, in time and in a proper and structured way. We were a good team to work together, everyone had their own visions on the project but we discussed a lot and finally we can say that everyone their ideas are visible in the SSV. In week 11 we were given one point for design at due to all the time we spend on design we are all glad for ourselves.

The communication is very difficult when you exist of a group of six people. Mostly when we had to discuss a small part of the project during one of our other lessons, not always everyone was given the information for that meeting. But in general the use of Dropbox, Facebook and GSM were proper channels to communicate with all the team members.

Team LOUIS XIV wants to thank the coach Hu Yunhao for the information he gave during the whole project.

4 Appendix

Annex 1: Data sheet of the motor

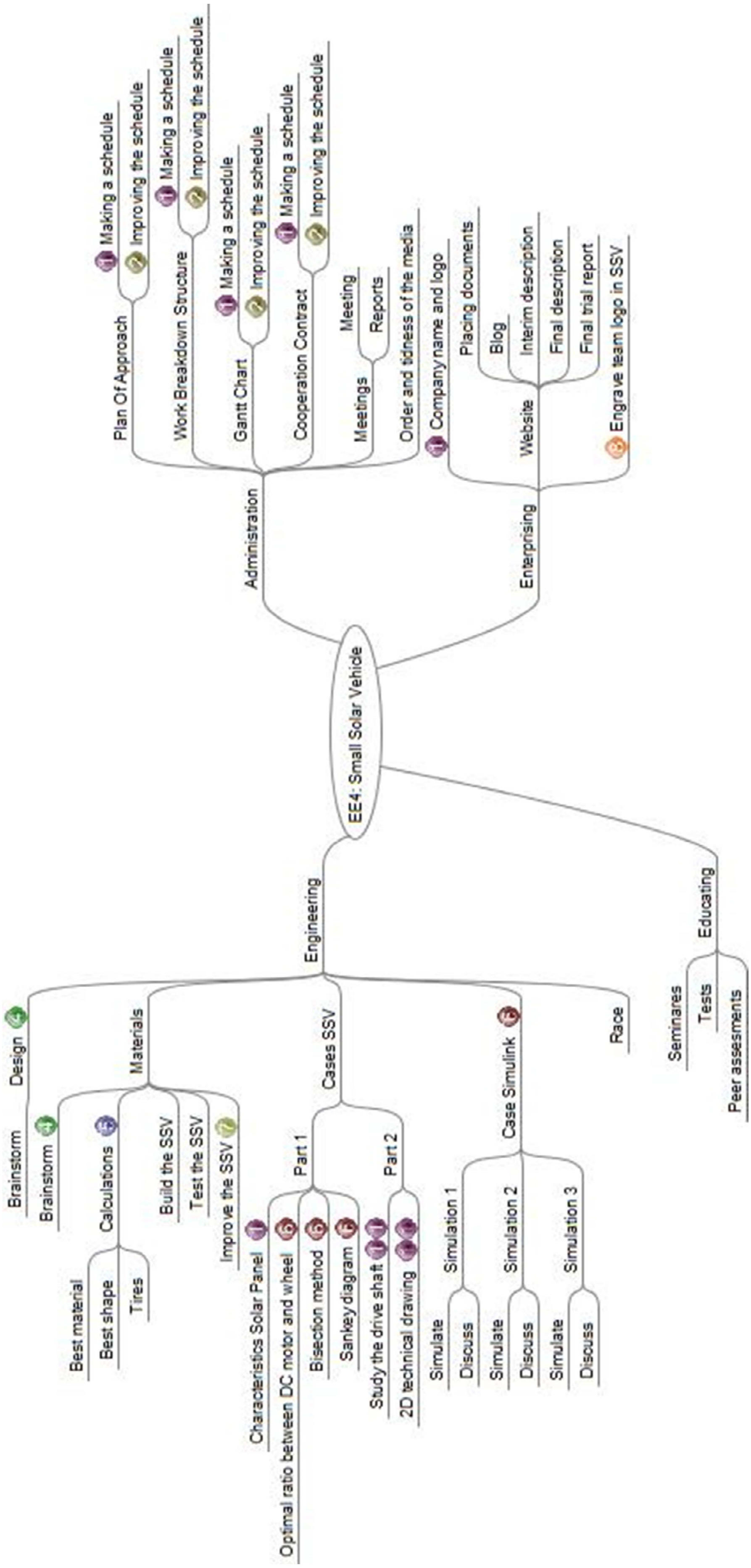
DC motor data sheet

	Motor Data: with CLL		Order Numb 110117	110119
1	Assigned power rating	W	5.0	5.0
2	Nominal voltage	Volt	6.0	9.0
3	No load speed	rpm	9630	9970
4	Stall torque	mNm	20.7	23.2
5	Speed/torque gradient	rpm/mNm	469	433
6	No load current	mA	30	21
7	Starting current	mA	3510	2710
8	Terminal resistance	Ohm	1.71	3.32
9	Max. permissible speed	rpm	10600	10600
10	Max. continuous current	mA	840	751
11	Max. continuous torque	mNm	4.96	6.43
12	Max. power output at nominal voltage	mW	5210	6030
13	Max. efficiency	%	83	84
14	Torque constant	mNm/A	5.90	8.55
15	Speed constant	rpm/V	1620	1120
16	Mechanical time constant	ms	19	19
17	Rotor inertia	gcm^2	3.88	4.10
18	Terminal inductance	mH	0.11	0.22
19	Thermal resistance housing-ambient	K/W	20	20
20	Thermal resistance rotor-housing	K/W	6.0	6.0
21	Thermal time constant winding	s	9	10

Annex 2: Parameters of the SSV

		Parameters		
		110117		
Short circuit current	Isc	0,57	A	
Diode factor	m	1,231		
Speed constant	Ke	1120	rpm/v	
Torque constant	Kt	8,55	mNm/A	
Internal resistance	Ra	3,32	Ω	
Solar car total mass	M	1	kg	
Solar car driving wheel diameter	ra	0,055	m	
Rolling resistance coefficient	Crr	0,012		
Air drag coefficient	Cw	0.5		
Frontal area	A	0,03	m^2	sin(30°)*0,26*0,23
Air density	ρ	1,293	kg/m^3	
Track slope	α	7,18	°	
Weight SSV without solar panel	m(without)	508,74	g	
Weight SSV with solar panel	m	886,02	g	
Weight on front wheels	m(frontwheels)	301,7	g	885,8 g together
Weight on back wheels	m(backwheels)	584,1	g	

Annex 3: WBS of team Louis XIV



Annex 4: Gantt chart of team Louis XIV

Team name
LOUIS XIV
Logo

Team members:
Arne Claes
Alexander De Baere
Bram Dezwart
Glen Pelgrims
Ellen Van Dievel
Inge Van Mieghem

Gantt chart

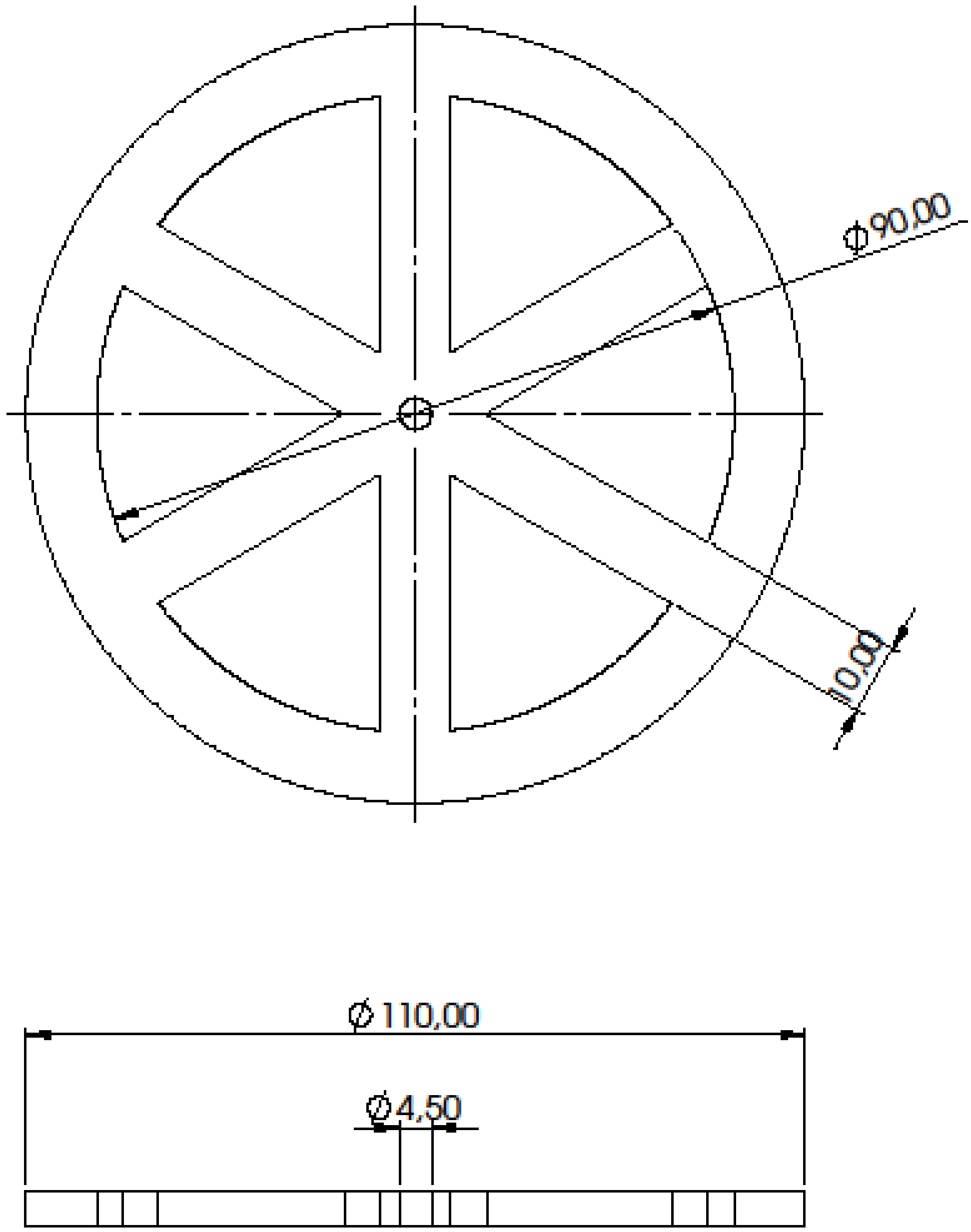
EE4: Small Solar Vehicle

Work assignments	Tasks	Subtasks		time span (wk)	total planned duration of wo (h)	total actual working hours (h)	Arne Claes: anticipated working (h)	Arne Claes: actual working hours (h)	Alexander De Baere: anticipated working (h)	Alexander De Baere: actual working hours (h)	Bram Dezwart: anticipated working (h)	Bram Dezwart: actual working hours (h)	Glen Pelgrims: anticipated working (h)	Glen Pelgrims: actual working hours (h)	Ellen Van Dievel: anticipated working (h)	Ellen Van Dievel: actual working hours (h)	Inge Van Mieghem: anticipated working (h)	Inge Van Mieghem: actual working hours (h)
1. Administration	1.1 Plan Of Approach	1.1.1 Making a schedule		1	2	2											2	2
		1.1.2 Improving the schedule		1	3,5	1	0,5	0	0,5	0	0,5	0	0,5	0	0,5	0	1	1
	1.2 Work Breakdown Structure	1.2.1 Making a schedule		1	2	1,5									2	1,5		
		1.2.2 Improving the schedule		1	4	1,5	0,5	0	0,5	0	0,5	0	0,5	0	1	0,5	1	1
	1.3 Gantt Chart	1.3.1 Making a schedule		1	3	4							3	3				1
		1.3.2 Improving the schedule		1	4	5,5	0,5		0,5	0	0,5	0	1	4	0,5	0,5	1	1
	1.4 Coöperation contract	1.4.1 Making a contract		1	2	1,5			2	1,5								
		1.4.2 Improving the contract		1	2,5	1,5	0,5	0	1	0,5	0,5	0	0,5	0				1
	1.5 Meetings	1.5.1 Meeting		11	132	130	22	22	22	22	22	22	22	20	22	22	22	22
		1.5.2 Reports		11	3	5	3	5										
	1.6 Order and tidiness of the media			11	3	4	3	3										1
2. Engineering	2.1 Design	2.1.1 Brainstorm		3	15	36	3	6	3	6	3	6	2	6	2	6	2	6
	2.2 Materials	2.2.1 Brainstorm		3	14	12	2	2	3	2	2	2	3	2	2	2	2	2
		2.2.2 Calculations	2.2.2.1 Best material	3	17	9	2	2	4	2	2	2	4	1	2	1	3	1
			2.2.2.2 Best shape	3	17	9	2	2	4	2	2	2	4	1	2	1	3	1
			2.2.2.3 Tires	3	14	9	2	2	3	2	2	2	3	1	2	1	2	1
		2.2.3 Build the SSV		4	24	27	4	5	4	5	4	7	4	2	4	2	4	6
		2.2.5 Improve the SSV		3	14	17	2	4	3	2	2	5	3	2	2	2	2	2
	2.3 Cases SSV	2.3.1 Part 1	2.3.1.1 Determine the characteristics of the solar panel	5	20	14	3	1	3	1	4	2	3	1	4	6	3	3
			2.3.1.2 Calculate the optimal ratio between the DC motor and the wheel	5	14	6	2	0	2	0	3	0	2	0	3	0	2	6
			2.3.1.3 Bisection method	5	14	7,5	2	2	2	3	3	2	2	0	3		2	0,5
			2.3.1.4 Sankey diagram	5	14	11,5	2	0	2	11	3	0	2	0	3	0	2	0,5
		2.3.2 Part 2	2.3.2.1 Testing the SSV	5	14	6	2	1	2	1	3	1	2	1	3	1	2	1
			2.3.2.2 Study of the drive shaft	5	14	12	2	6	2	0	3	0	2	0	3	0	2	6
			2.3.2.3 2D technical drawing	5	13	15	1	0	1	0	4	6	1	0,5	4	8	2	0,5
	2.4 Case Simulink	2.4.1 Simulation 1	2.4.1.1 Simulate	5	14	9	2	0	2	0	2	0	3	3	2	3	3	3
			2.4.1.2 Discuss	5	6	3	1	0	1	0	1	0	1	1	1	1	1	1
		2.4.2 Simulation 2	2.4.2.1 Simulate	5	14	13	2	0	2	0	2	0	3	6	2	4	3	3
			2.4.2.2 Discuss	5	6	3	1	0	1	0	1	0	1	1	1	1	1	1
		2.4.3 Simulation 3	2.4.3.1 Simulate	5	14	19	2	0	2	0	2	0	3	11	2	5	3	3
			2.4.3.2 Discuss	5	6	3	1	0	1	0	1	0	1	1	1	1	1	1
	2.5 Race			3	18	18	3	3	3	3	3	3	3	3	3	3	3	3
3. Enterprising	3.1 Company name and logo			1	6	3	1	0,5	1	0,5	1	0,5	1	0,5	1	0,5	1	0,5
	3.2 Website	3.2.1 Placing documents		11	12	10	4	2	1	0,5	4	6	1	0,5	1	0,5	1	0,5
		3.2.2 Blog		11	22	12	5	5	3	0,5	5	5	3	0,5	3	0,5	3	0,5
		3.2.3 Interim description		5	8	6	1	1	1	1	1	1	1	1	2	1	2	1
		3.2.4 Final description		5	30	14	5	3	5	5	5	1	5	1	5	1	5	3
		3.2.5 Final trial report		5	30	16	5	2	5	5	5	3	5	2	5	2	5	2
	3.3 Engrave team logo in SSV			2	6	6	1	1	1	1	1	1	1	1	1	1	1	1
4. Educating	4.1 Seminares			5	120	120	20	20	20	20	20	20	20	20	20	20	20	20
	4.2 Tests			12	24	24	4	4	4	4	4	4	4	4	4	4	4	4
	4.3 Peer assessments			2	6	6	1	1	1	1	1	1	1	1	1	1	1	1
Total					721	634	120	106	119	103	123	105	122	102	120	104	118	115

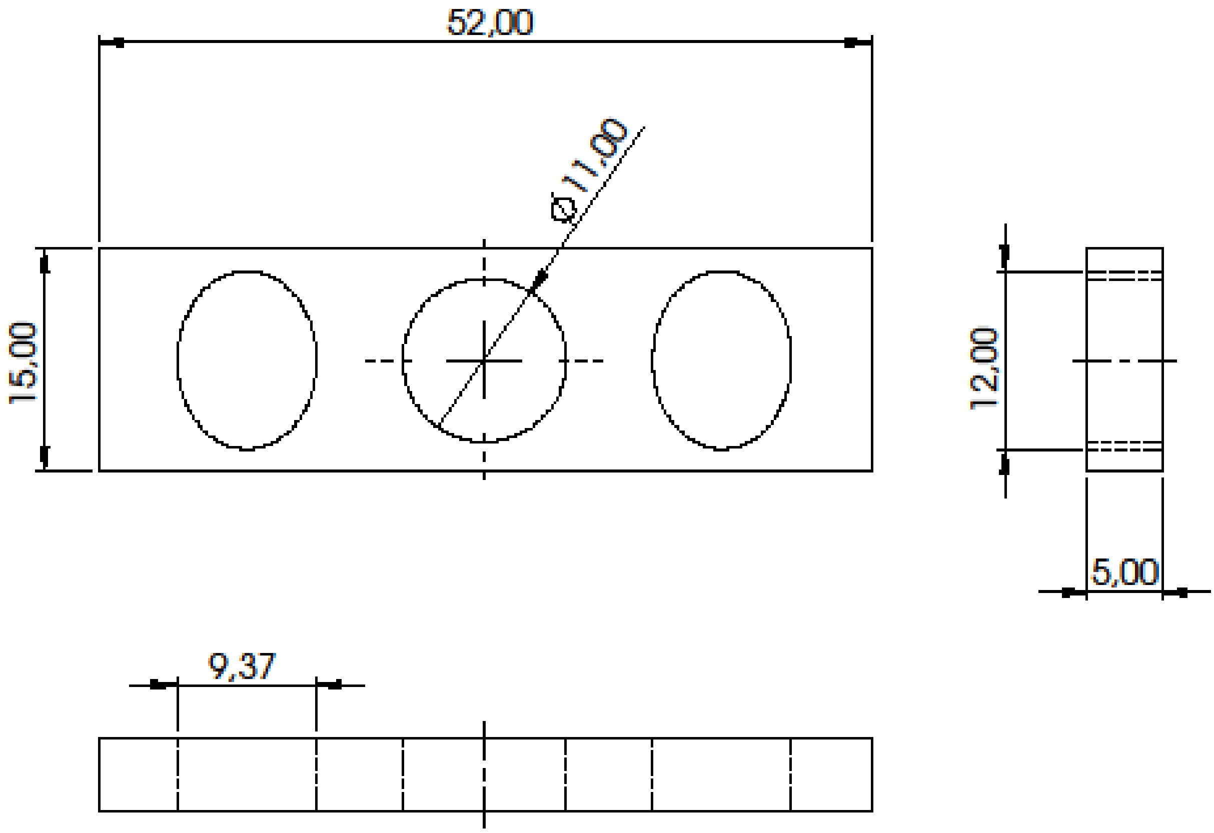
Weeks: 1 2 3 4 5 6 7 8 9 10 11 12 13 14

Legend:
Responsible for that subtask
Sequence in which we shall fulfill the tasks

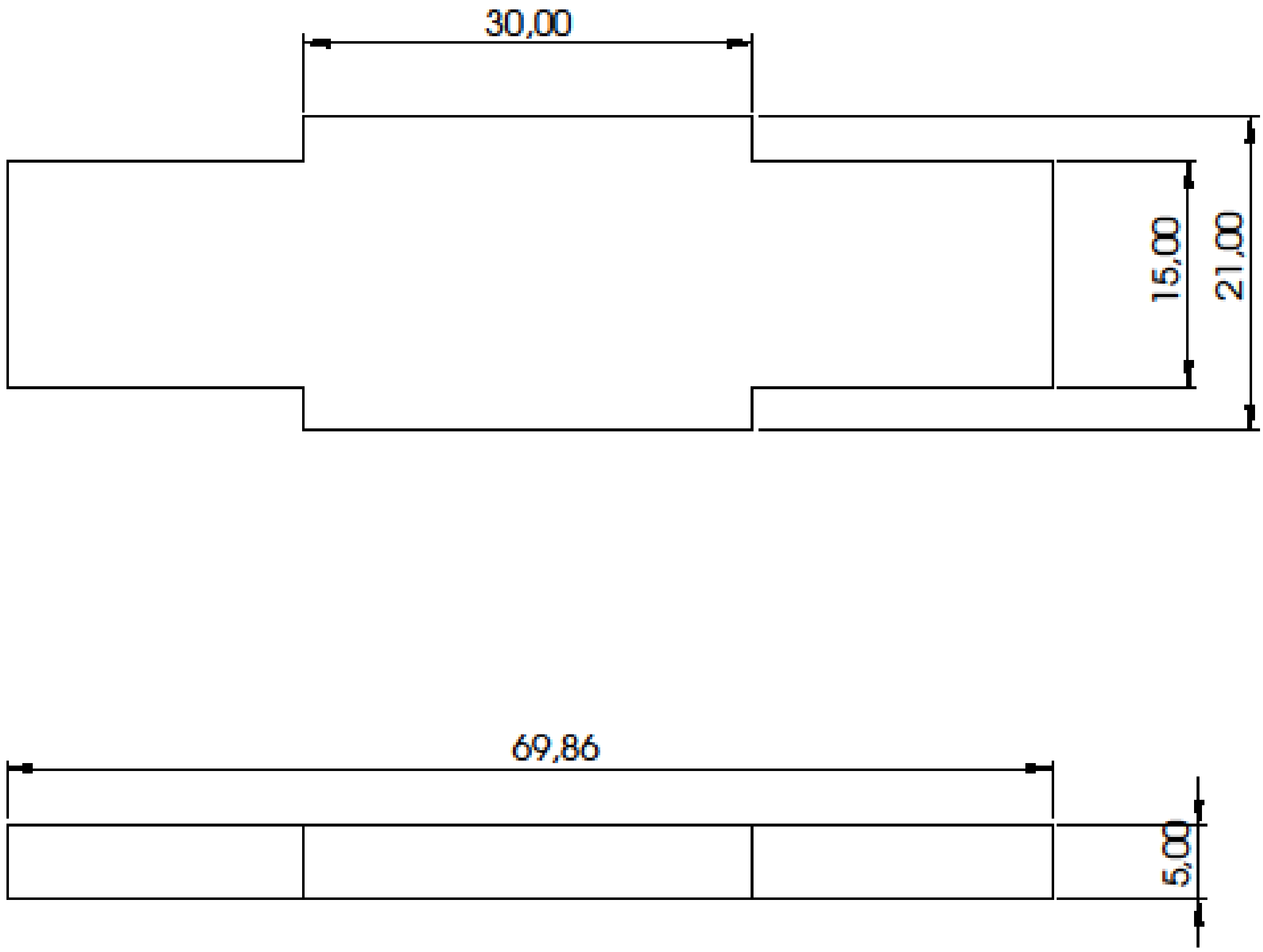
Annex 5: 2D drawings of parts of the SSV



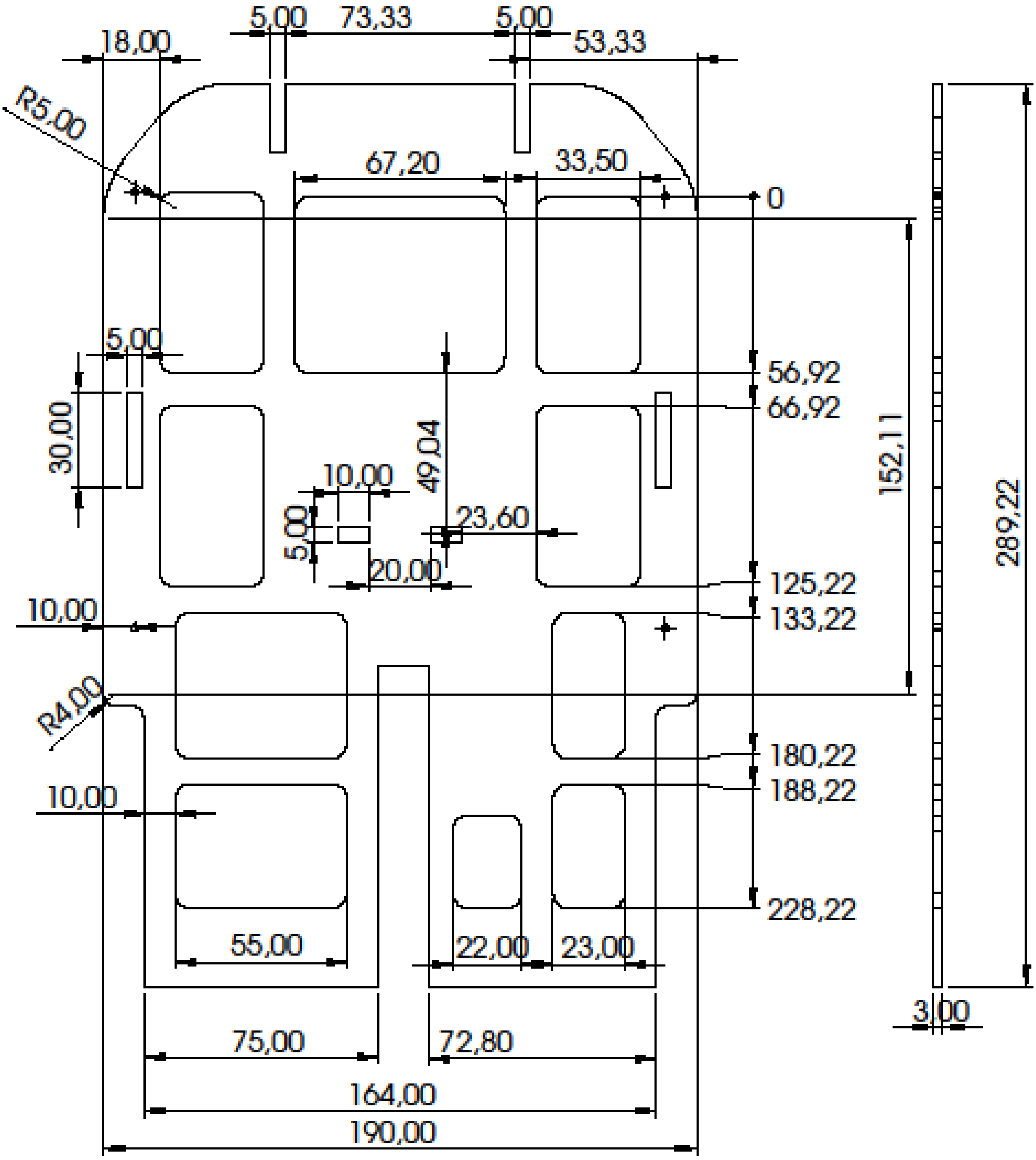
RUWHEID VOLGENS NEN 3634	MAATTOLERANTIES VOLGENS NEN 2365	MATERIAAL Acrylic (Medium-high impact)	VORM- EN PLAATSTOL. VOLGENS NEN 3311
PROJECTIE	SCHAAL 1:1	GETEKEND –	OPMERKINGEN
	MAATEENHEID mm	GROEPSL. –	–
	DATUM 8/05/2013	GECONTR. –	
		Rear wheel	NUMMER – A4



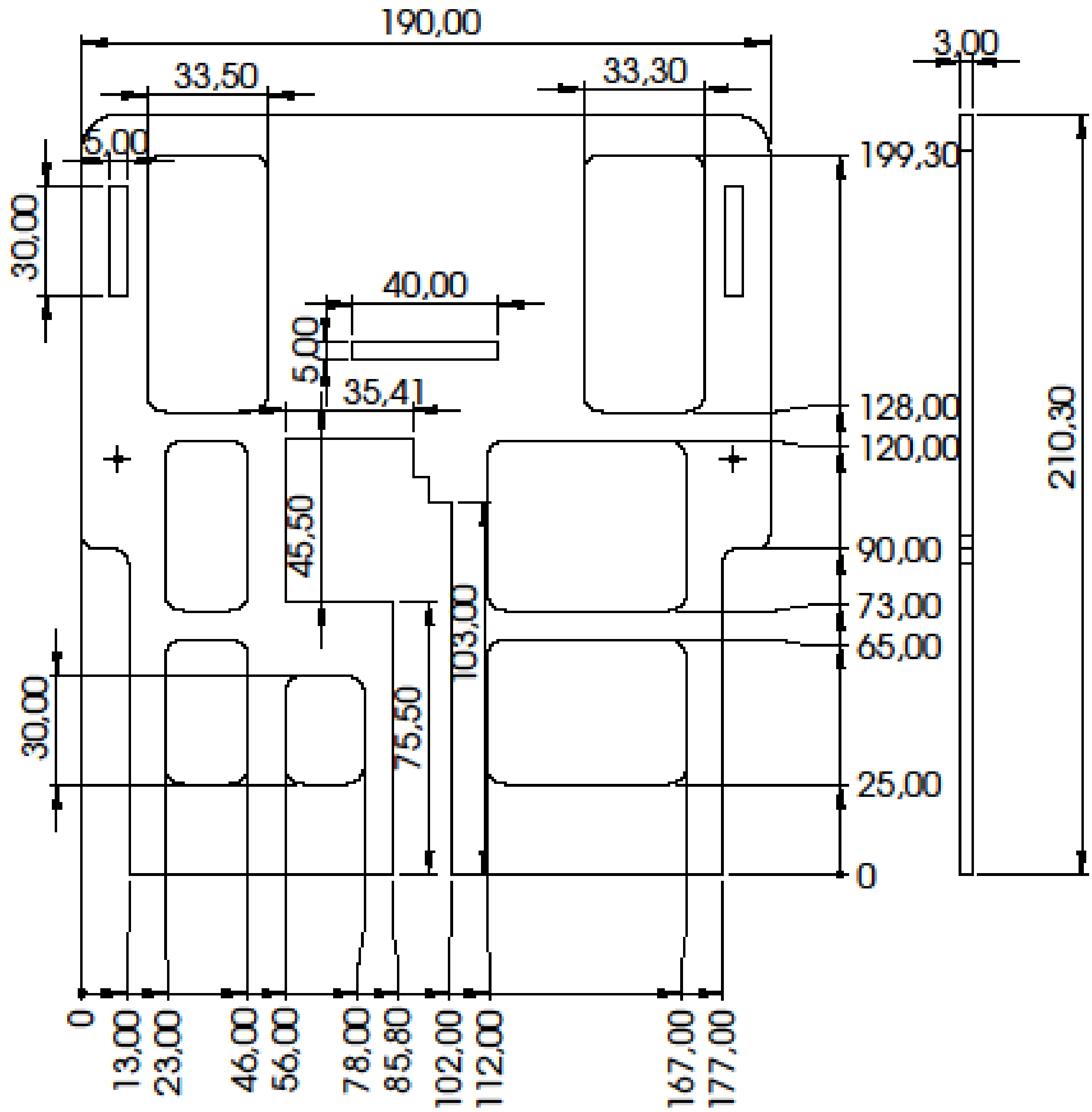
RUWHEID VOL-GENS NEN 3634	MAATTOLERANTIES VOLGENS NEN 2365	MATERIAAL Acrylic (Medium-high impact)	VORM- EN PLAATSTOL. VOLGENS NEN 3311
PROJECTIE	SCHAAL 2:1	GETEKEND Alexander De Baere	OPMERKINGEN
	MAATEENHEID mm	GROEPSL. Inge Van Mieghem	–
	DATUM 9/05/2013	GECONTR. Ellen Van Dievel –	
		Bearing holder	NUMMER – A4



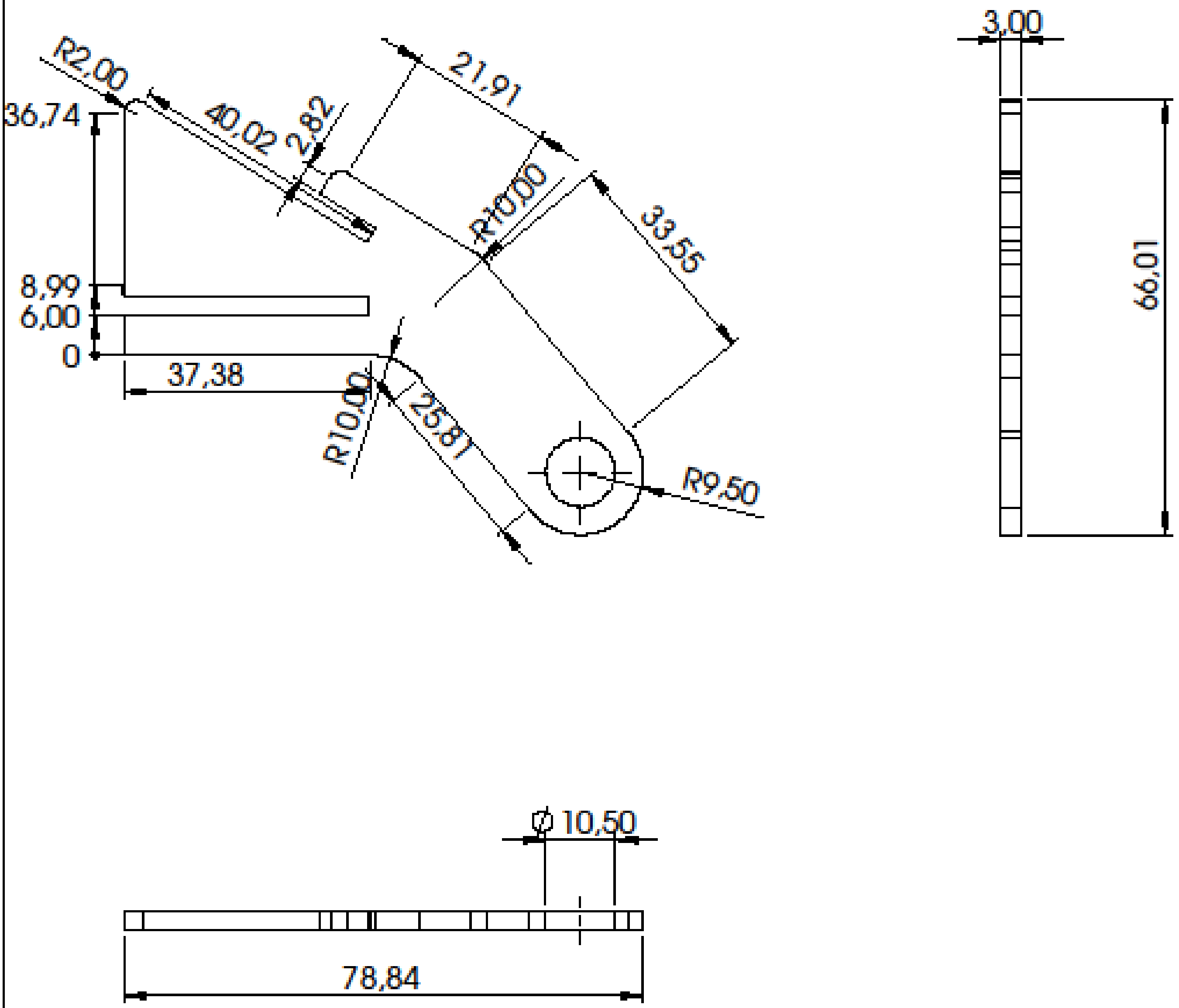
RUWHEID VOLGENS NEN 3634	MAATTOLERANTIES VOLGENS NEN 2365	MATERIAAL Acrylic (Medium-high impact)	VORM- EN PLAATSTOL. VOLGENS NEN 3311
PROJECTIE	SCHAAL 2:1	GETEKEND Alexander De Baere	OPMERKINGEN
	MAATEENHEID mm	GROEPSL. Inge Van Mieghem	–
	DATUM 9/05/2013	GECONTR. Ellen Van Dievel –	
	Big spacer	NUMMER –	A4



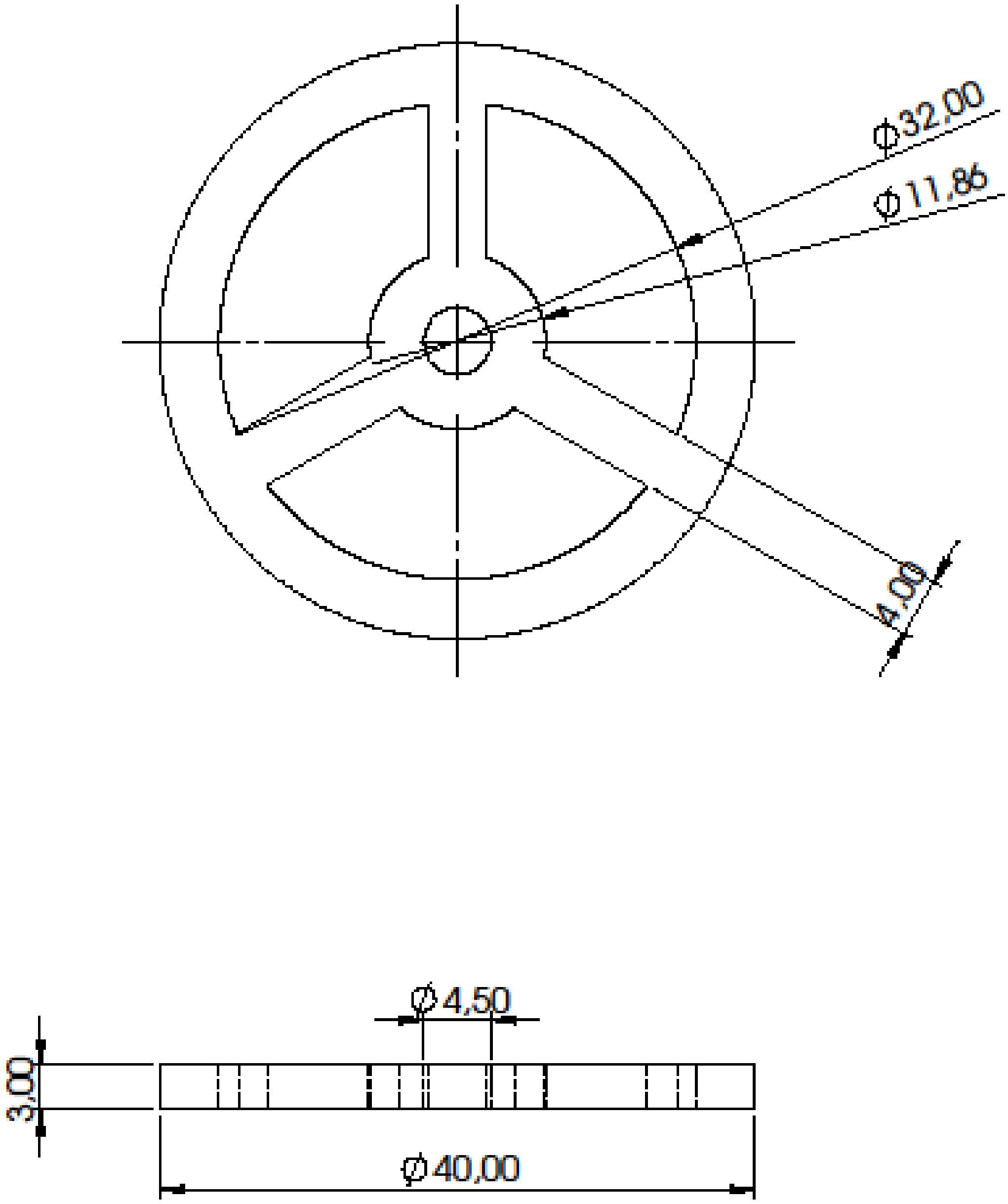
RUWHEID VOLGENS NEN 3634	MAATTOLERANTIES VOLGENS NEN 2365	MATERIAAL Acrylic (Medium-high impact)	VORM- EN PLAATSTOL. VOLGENS NEN 3311
PROJECTIE	SCHAAL 1:2	GETEKEND Bram Dezwart –	OPMERKINGEN
	MAATEENHEID mm	GROEPSL. Inge Van Mieghem –	–
	DATUM 9/05/2013	GECONTR. Ellen Van Dievel –	
	Frame underside		NUMMER – A4



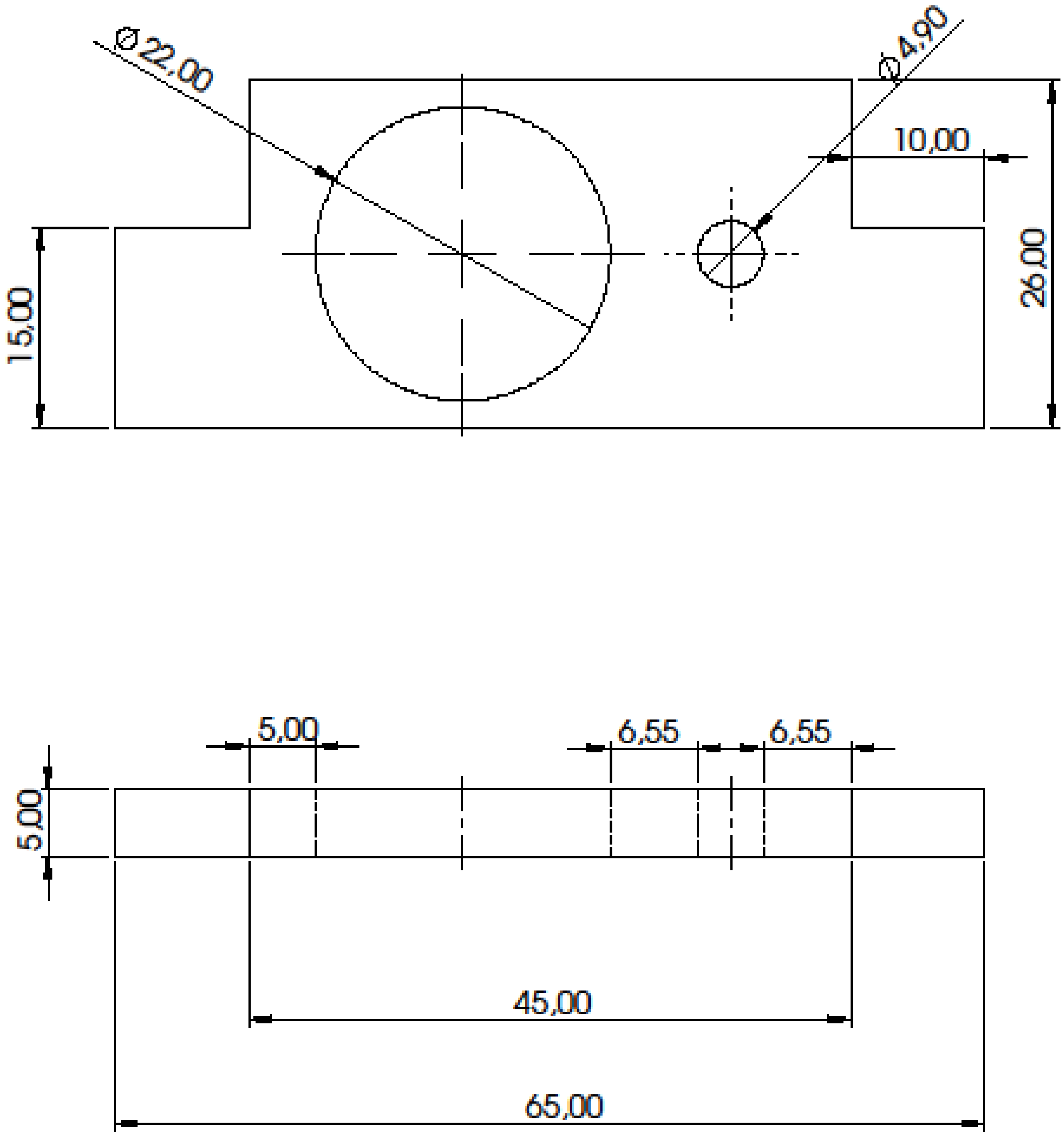
RUWHEID VOLGENS NEN 3634	MAATTOLERANTIES VOLGENS NEN 2365		MATERIAAL Acrylic (Medium-high impact)		VORM- EN PLAATSTOL. VOLGENS NEN 3311
PROJECTIE	SCHAAL	1:2	GETEKEND	Bram Dezwart –	OPMERKINGEN
	MAATEENHEID	mm	GROEPSL.	Inge Van Mieghem –	
	DATUM	9/05/2013	GECONTR.	Ellen Van Dievel –	
	Frame upperside				NUMMER – A4



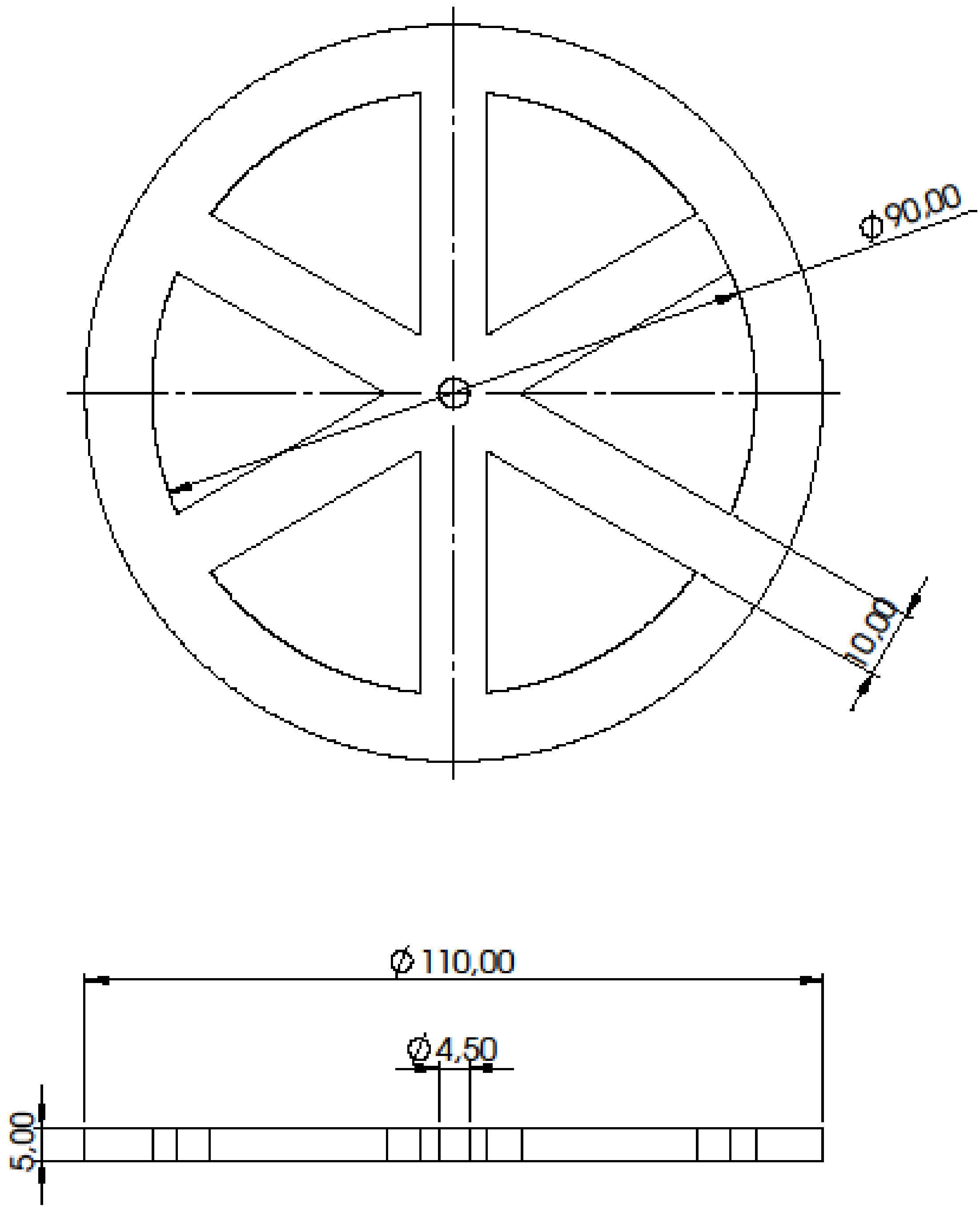
RUWHEID VOLGENS NEN 3634	MAATTOLERANTIES VOLGENS NEN 2365	MATERIAAL Acrylic (Medium-high impact)	VORM- EN PLAATSTOL. VOLGENS NEN 3311
PROJECTIE	SCHAAL 1:1 MAATEENHEID mm DATUM 9/05/2013	GETEKEND Alexander De Baere GROEPSL. Inge Van Mieghem GECONTR. Ellen Van Dievel –	OPMERKINGEN –
		Front wheel holder	NUMMER – / A4



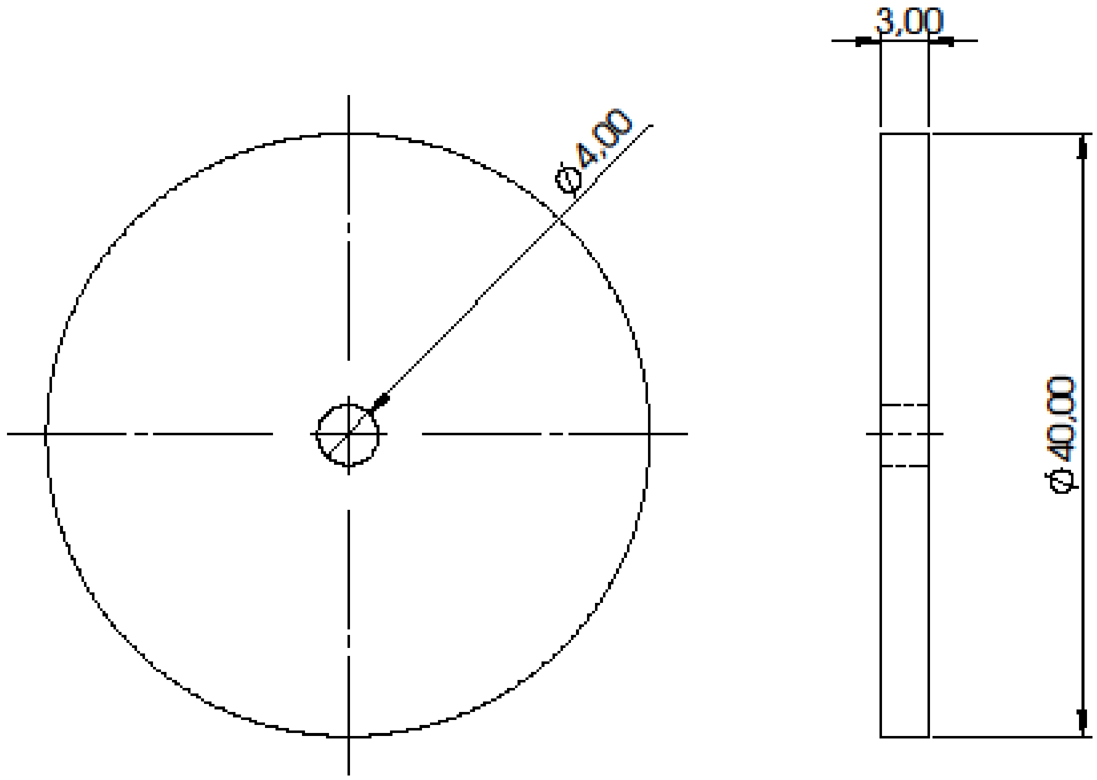
RUWHEID VOLGENS NEN 3634	MAATTOLERANTIES VOLGENS NEN 2365		MATERIAAL Acrylic (Medium-high impact)	VORM- EN PLAATSTOL. VOLGENS NEN 3311
PROJECTIE	SCHAAL	2:1	GETEKEND Bram Dezwart –	OPMERKINGEN
	MAATEENHEID	mm	GROEPSL. Inge Van Mieghem –	–
	DATUM	9/05/2013	GECONTR. Ellen Van Dievel –	
		Front wheel		NUMMER – A4



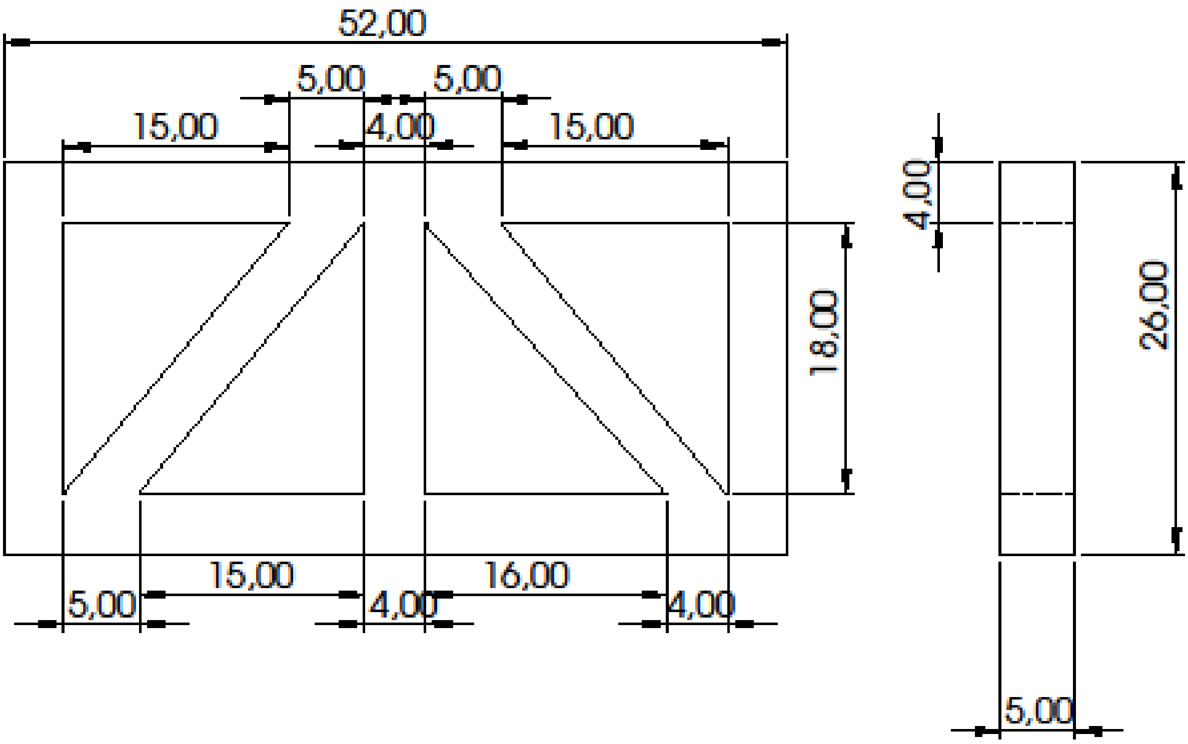
RUWHEID VOLGENS NEN 3634	MAATTOLERANTIES VOLGENS NEN 2365		MATERIAAL Acrylic (Medium-high impact)		VORM- EN PLAATSTOL. VOLGENS NEN 3311
PROJECTIE	SCHAAL	2:1	GETEKEND Alexander De Baere	–	OPMERKINGEN
	MAATEENHEID	mm	GROEPSL. Inge Van Mieghem	–	–
	DATUM	9/05/2013	GECONTR. Ellen Van Dievel	–	
	Holder of the motor				NUMMER – A4



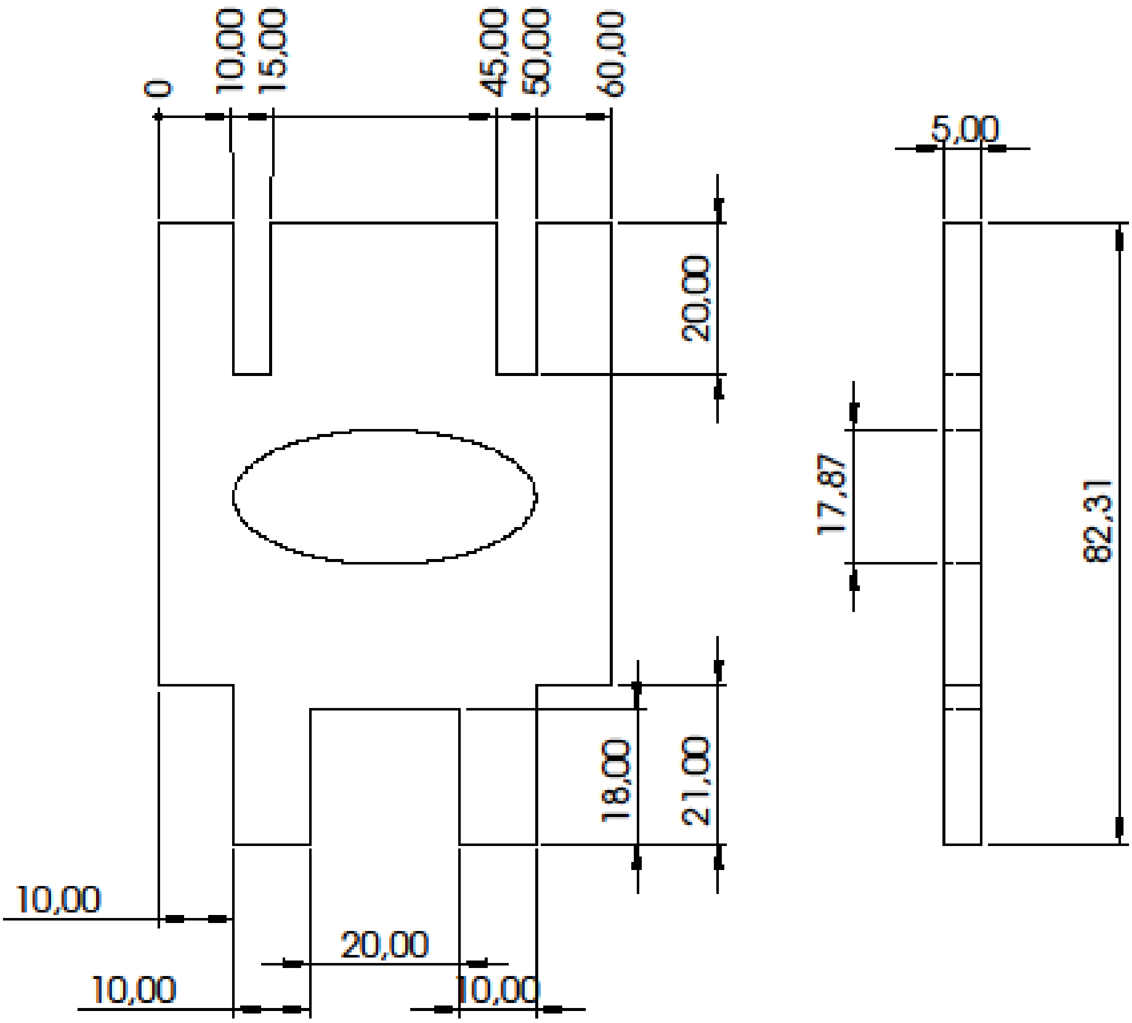
RUWHEID VOLGENS NEN 3634	MAATTOLERANTIES VOLGENS NEN 2365	MATERIAAL Acrylic (Medium-high impact)	VORM- EN PLAATSTOL. VOLGENS NEN 3311
PROJECTIE	SCHAAL 1:1	GETEKEND Bram Dezwart –	OPMERKINGEN
	MAATEENHEID mm	GROEPSL. Inge Van Mieghem –	
	DATUM 9/05/2013	GECONTR. Ellen Van Dievel –	
	Rear wheel		NUMMER – A4



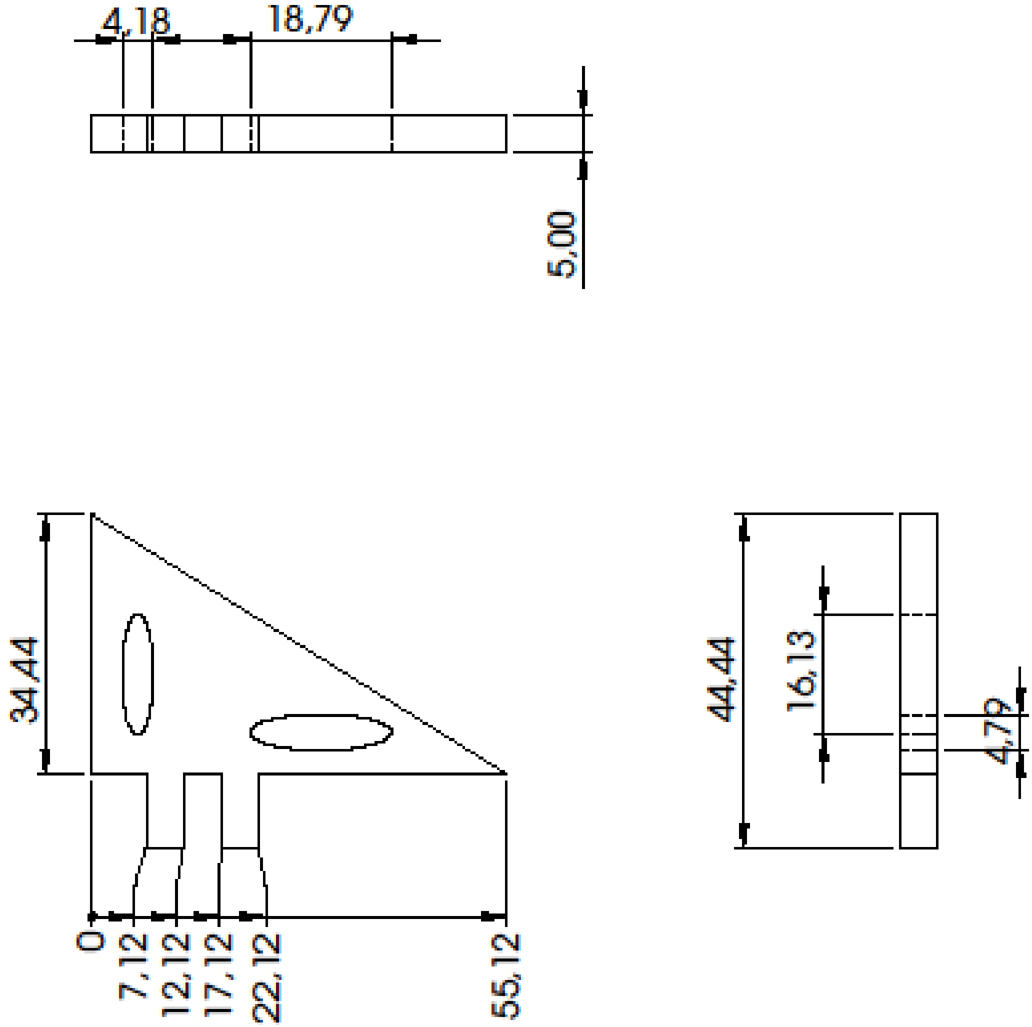
RUWHEID VOLGENS NEN 3634	MAATTOLERANTIES VOLGENS NEN 2365	MATERIAAL Acrylic (Medium-high impact)	VORM- EN PLAATSTOL. VOLGENS NEN 3311
PROJECTIE	SCHAAL 2:1	GETEKEND Alexander De Baere –	OPMERKINGEN
	MAATEENHEID mm	GROEPSL. Inge Van Mieghem –	–
	DATUM 9/05/2013	GECONTR. Ellen Van Dievel –	
	Side wheel	NUMMER –	A4



RUWHEID VOLGENS NEN 3634	MAATTOLERANTIES VOLGENS NEN 2365	MATERIAAL Acrylic (Medium-High Impact)	VORM- EN PLAATSTOL. VOLGENS NEN 3311
PROJECTIE	SCHAAL 2:1	GETEKEND Alexander De Baere	OPMERKINGEN
	MAATEENHEID mm	GROEPSL. Inge Van Mieghem	
	DATUM 9/05/2013	GECONTR. Ellen Van Dievel	
	Small Spacer	NUMMER	A4



RUWHEID VOLGENS NEN 3634	MAATTOLERANTIES VOLGENS NEN 2365	MATERIAAL Acrylic (Medium-high impact)	VORM- EN PLAATSTOL. VOLGENS NEN 3311
PROJECTIE	SCHAAL 1:1	GETEKEND Alexander De Baere –	OPMERKINGEN
	MAATEENHEID mm	GROEPSL. Inge Van Mieghem –	–
	DATUM 9/05/2013	GECONTR. Ellen Van Dievel –	
	Solar panel holder part 1		NUMMER – A4



RUWHEID VOLGENS NEN 3634	MAATTOLERANTIES VOLGENS NEN 2365		MATERIAAL Acrylic (Medium-high impact)		VORM- EN PLAATSTOL. VOLGENS NEN 3311	
PROJECTIE	SCHAAL	1:1	GETEKEND Alexander De Baere	–	OPMERKINGEN	
	MAATEENHEID	mm	GROEPSL. Inge Van Mieghem	–	–	
	DATUM	9/05/2013	GECONTR. Ellen Van Dievel	–		
	Solar panel holder part 2				NUMMER –	A4